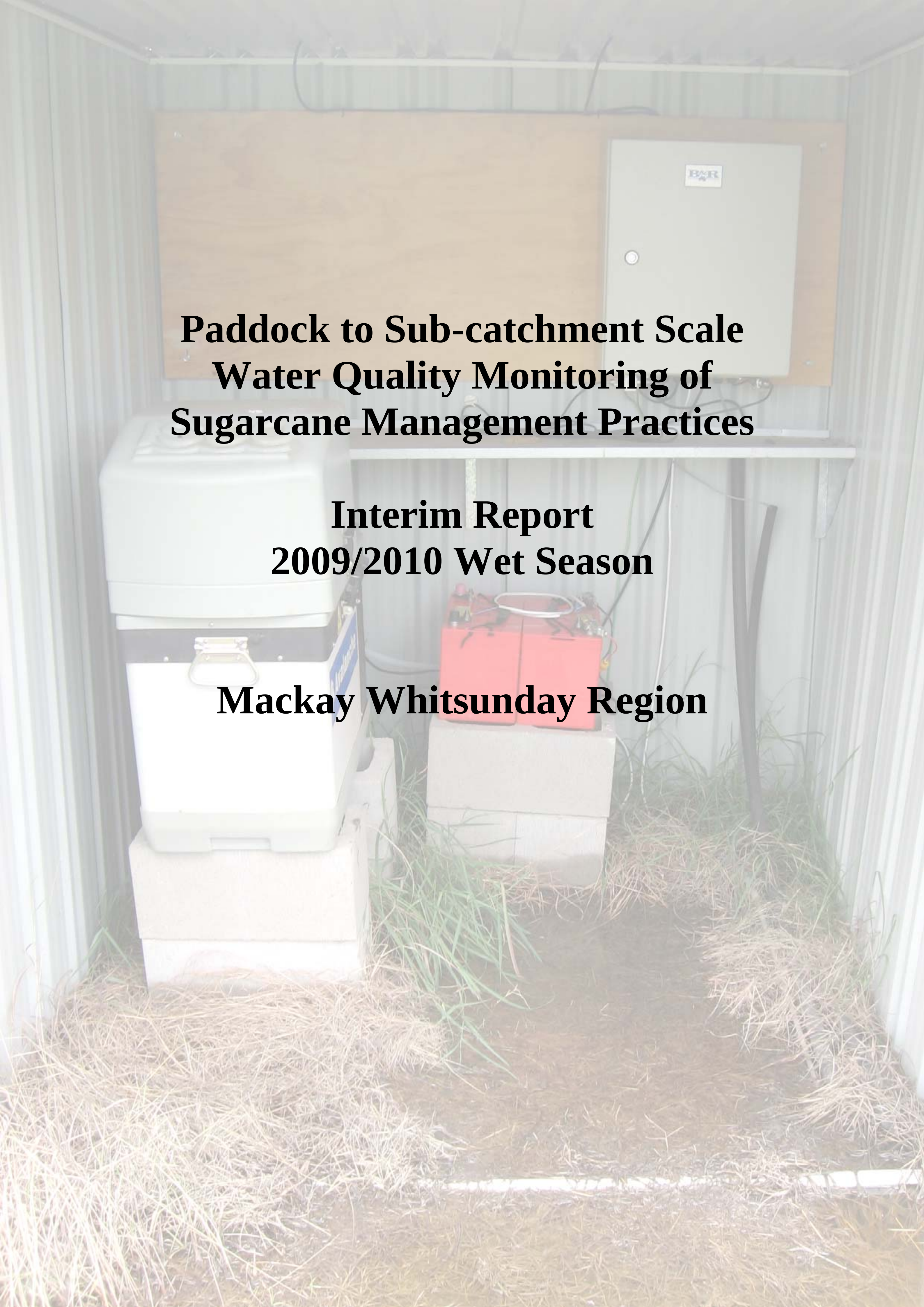

# Paddock to Sub-catchment Scale Water Quality Monitoring of Sugarcane Management Practices

## Interim Report
## 2009/2010 Wet Season

## Mackay Whitsunday Region

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## Mackay Whitsunday Region

**K. Rohde[1] and A. Bush[1]**

**Funding provided by Reef Catchments Mackay Whitsunday Inc. through the Paddock to Reef Integrated Monitoring, Modelling and Reporting Program and Project Catalyst**

[1] Department of Environment and Resource Management
Mackay, QLD 4740
Phone: (07) 4967 0725
Fax: (07) 4957 4005
Email: Ken.Rohde@derm.qld.gov.au

Prepared by:
Planning and Assessment, Mackay
Department of Environment and Resource Management

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# EXECUTIVE SUMMARY

The Australian federal government and the Queensland state government are committed to improving the water quality in the Great Barrier Reef (GBR) lagoon to ensure the continued survival of the GBR as a healthy functional reef ecosystem. The Reef Water Quality Protection Plan (Reef Plan) was released by the state and federal governments and subsequently reviewed and updated in 2009 and released as the Reef Plan (The State of Queensland and Commonwealth of Australia 2009). The Reef Plan has two goals; to halt and reverse the decline in water quality entering the reef by 2013 and to ensure that by 2020 the quality of water entering the reef from adjacent catchments has no detrimental impact on the health and resilience of the reef.

To achieve the plan, investments are made through Reef Rescue, industry and voluntarily to improve management practices at a farm scale. Thus it is important to study the effectiveness of the management practices in improving water quality at the paddock scale. In conjunction with this plan, the Paddock to Reef Monitoring, Modelling and Reporting (P2R) Program is using multiple lines of evidence to report on the effectiveness of these investments and whether targets are being met (Carroll *et al.* in press). One of these lines of evidence is practice effectiveness in improving water quality at the paddock (edge-of-field) scale.

Under the P2R program, paddock scale monitoring of water quality from various levels of management practices was implemented in selected GBR catchments and agricultural industries (Carroll *et al.* in press). As part of this program and Project Catalyst, two cane blocks in the Mackay Whitsunday region are being used to measure levels of herbicides, nutrients and sediments in runoff under different cane management strategies with the emphasis on improving water quality with improved management practices.

The Victoria Plains site (uniform cracking clay) was divided into two treatments of soil, nutrient and herbicide management practices. The Marian site (duplex soil) was divided into five treatments. Each treatment was instrumented to measure runoff and collect samples for water quality analyses (total suspended solids, total and filtered nutrients, and herbicides).

Results from the first year of monitoring indicate the following conclusions:

At the Victoria Plains site (cracking clay):

- Total runoff from individual runoff events from Treatment 2 (1.8 m row spacing; controlled traffic) averaged 18% less than Treatment 1 (1.5 m row spacing) (665 and 810 mm, respectively from 1636 mm rainfall). Runoff from Treatment 2 was delayed by ~6 minutes compared with Treatment 1, and the peak runoff rate was ~2% lower, all contributing to reduced runoff.
- Total suspended solids (TSS) concentrations varied considerably across the samples and across both treatments revealing no obvious seasonal trends, but increasing peak runoff rates tended to produce higher TSS concentrations. Average TSS concentrations were slightly higher in Treatment 1 (1.5 m row spacing; 826 mg/L) than Treatment 2 (1.8 m row spacing; 631 mg/L).

- Total soil loss is unknown due to some runoff events not being sampled, but it is estimated to be 5-10 t/ha.
- Initial nitrogen oxide ($NO_x$) concentrations in runoff water were three-fold higher from Treatment 1 (133 kg N/ha applied) than Treatment 2 (38 kg N/ha applied). The total wet season loss of $NO_x$ in runoff from Treatment 1 was 13.0 kg/ha, whereas Treatment 2 was 4.85 kg/ha; 9.8% and 12.8% of the applied nitrogen for Treatment 1 and Treatment 2, respectively.
- Filterable reactive phosphorus (FRP) concentrations were similar between treatments (average 31-34 µg P/L), as the same amount of phosphorus was applied to both treatments. Concentrations declined throughout the season.
- Herbicide residues of diuron and hexazinone were particularly elevated in the first two runoff events (within 14 days of application) from Treatment 1 (Velpar K4 applied). These two runoff events represented 64% and 91% of the season's diuron and hexazinone losses, respectively (but only 11% of the runoff). Atrazine residues were detected in both treatments, despite not being applied during our study.

At the Marian site (duplex soil):

- Total runoff was compounded by the site flooding several times, so it is not possible to derive accurate runoff figures. Our best estimate is 720 mm runoff (1.8 m row spacing) from 1783 mm rainfall.
- Total suspended solids concentrations were much lower than the Victoria Plains site (treatment averages 92-143 mg/L), presumably due to the harder setting soil and lower slope at this site.
- Nitrogen oxide concentrations were similar between the five treatments, and showed a decline through the season. Initial concentrations were 400-600 µg N/L, at least 10-fold less than the Victoria Plains site (fertiliser applied to both sites at a similar time). Surface soil $NO_x$ concentrations were three-fold less at the Marian site, contributing to the lower concentrations in runoff.
- In contrast to $NO_x$, average FRP concentrations (347-563 µg P/L) were 10-fold more than those detected at the Victoria Plains site. Surface soil phosphorus levels at the Marian site were more than four times higher than the Victoria Plains site, contributing to the higher FRP concentrations.
- Initial herbicide concentrations were much lower than those detected at the Victoria Plains site, but still declined through the season. Herbicides were applied 88 days prior to the first runoff event, compared to 8 days at the Victoria Plains site.

In summary:

- Results show the importance of soil traits, input application rates, duration between application and the first runoff event, and the value of antecedent infiltrating rainfall or irrigation on nutrient and herbicide losses in runoff.
- Higher nitrogen inputs and high background soil phosphorus levels can lead to larger runoff losses.
- Matching row spacing to machinery track width can reduce runoff.
- The 1.5 m and 1.8 m row spacing treatments produced similar cane yields.

# 1 INTRODUCTION

Several water quality studies in the past decade have focussed on quantifying the pollutants generated by the major land uses within the Great Barrier Reef (GBR) catchments. Sugarcane has been found to export high concentrations (compared to “natural” sites) of dissolved inorganic nitrogen (DIN or $NO_x$, primarily nitrate) (Bainbridge *et al.* 2009; Bramley and Roth 2002; Hunter and Walton 2008; Rohde *et al.* 2008). The herbicide residues most commonly found in surface waters in the GBR region where sugarcane is grown (ametryn, atrazine, diuron and hexazinone) are largely derived from sugarcane landuse (Bainbridge *et al.* 2009; Faithful *et al.* 2006; Lewis *et al.* 2009; Rohde *et al.* 2008). Sediment fluxes are relatively low from sugarcane landuse due to management practice changes over the past twenty years. However, little is known about the water quality benefits of specific sugarcane management practices.

## 1.1 Project Intent

The purpose of the project is to reduce the amounts of herbicides, nutrients and sediments leaving sugarcane farms and entering the GBR lagoon. This will be achieved by providing growers involved in the delivery of the Australian government’s Reef Rescue program (see Section 1.3) with detailed information on how their management practices affect water quality. This will enable growers to refine their practices and further reduce the amounts of contaminants leaving the farm. Supporting farmers in this manner will allow for adaptive management of practice implementation to deliver the highest possible water quality benefits for the GBR. Practice refinements developed in this way will become a core part of future industry extension efforts. The project involves collaboration between AgriServ Central, Department of Environment and Resource Management, Reef Catchments Mackay Whitsunday Inc. and individual cane farmers involved in the project.

## 1.2 Reef Plan

To address the issue of declining water quality entering the GBR lagoon, the *Reef Water Quality Protection Plan* (Reef Plan) was endorsed by the Prime Minister and Premier in October 2003. It primarily built on existing government programs and community initiatives to encourage a more coordinated and cooperative approach to improving water quality.

An independent audit and report to the Prime Minister and the Premier of Queensland on the implementation of the Reef Plan was undertaken in 2005. Whilst the positive outcomes that were achieved over the period from 2003 to 2005 have been recognised, input from stakeholders and new scientific evidence confirmed the need to renew and reinvigorate the Reef Plan to ensure the goals and objectives will be met.

This updated Reef Plan (The State of Queensland and Commonwealth of Australia 2009) builds on the 2003 plan by targeting priority outcomes, integrating industry and community initiatives and incorporating new policy and regulatory frameworks. Reef Plan is now underpinned by clear and measurable targets, improved accountability and more comprehensive and coordinated monitoring and evaluation.

Reef Plan has two primary goals. The immediate goal is to halt and reverse the decline in water quality entering the reef by 2013. The long term goal is to ensure that by 2020 the quality of water entering the reef from adjacent catchments has no detrimental impact on the health and resilience of the reef. Achievement of these goals will be assessed against quantitative targets established for land management and water quality outcomes.

To help achieve the Reef Plan goals and objectives, three priority work areas (Focusing the Activity, Responding to the Challenge, Measuring Success) have been identified and specific actions and deliverables outlined for completion between now and 2013.

The plan will be reviewed again in 2013 to ensure that it is delivering the intended outcomes. Throughout the course of Reef Plan there will also be regular review and improvement of the plan to ensure its currency and effectiveness.

## 1.3 Reef Rescue

Reef Rescue is a key component of *Caring for our Country*, the Australian government’s $2.25 billion initiative to restore the health of Australia’s environment and to improve land management practices. Reef Rescue’s objective is to improve the water quality of the GBR lagoon by increasing the adoption of land management practices that reduce the runoff of nutrients, pesticides and sediment from agricultural land. The Reef Rescue component of Caring for our Country is comprised of five integrated components (http://www.nrm.gov.au/funding/2008/reef-rescue.html):

- Water quality grants ($146 million over five years)
- Reef partnerships ($12 million over five years)
- Land and Sea country Indigenous partnerships ($10 million over five years)
- Reef water quality research and development ($10 million over five years)
- Water quality monitoring and reporting, including the publication of an annual Great Barrier Reef water quality report card ($22 million over five years)

## 1.4 Water Quality Improvement Plans

The Mackay Whitsunday Reef Rescue delivery process is focused on the increased adoption of “A” and “B” class (cutting-edge and current best practice, respectively) land management practices (DPI&F 2009) across agricultural commodities in the region. These practices were identified in the *Mackay Whitsunday Water Quality Improvement Plan* (Drewry *et al.* 2008) and are based on the best available science and information with regards to improving on-farm economic and environmental sustainability. The objective of these practices is to improve the water quality of the GBR lagoon by reducing nutrient, pesticide and sediment loads whilst helping to improve farm productivity and profitability. The validation of new innovative practices and the monitoring of practice adoption rates will help determine natural resource condition (including water quality) improvements at a farm, sub-catchment, catchment and region wide scale.

## 1.5 Project Catalyst

*Project Catalyst* aims to quantify the water quality, productivity, social and economic benefits of adopting "cutting-edge" (A class) management practices in the sugar industry. The foundation partners of Project Catalyst are The Coca Cola Company, World Wildlife Fund and Reef Catchments Mackay Whitsunday Inc.

In 2009, Project Catalyst worked with 15 cane growers adopting A class management practices in the Mackay Whitsunday region. From 2010 to 2014, the project aims to translate the Mackay Whitsunday experience to A class cane growers throughout the GBR catchment, as well as to the global sugar industry.

## 1.6 Paddock to Reef Integrated Monitoring, Modelling and Reporting Program

The *Paddock to Reef Integrated Monitoring, Modelling and Reporting (P2R) Program* was implemented to determine the success of the Reef Plan in reducing anthropogenic contaminants entering the GBR lagoon (The State of Queensland 2009). The P2R Program is using multiple lines of evidence to report on the effectiveness of investments and whether targets are being met (Carroll *et al.* in press). One of these lines of evidence is practice effectiveness in improving water quality at the paddock (edge-of-field) scale. It combines on-ground end of paddock runoff, sub-catchment and catchment scale water quality monitoring within the GBR catchments with modelling at both paddock and catchment scales. At the catchment scale, water quality samples are to be collected for a three year period prior to and following the Reef Rescue regulations coming into effect to determine any change in water quality. At the paddock scale, plots will be established utilising differing levels of soil management, pesticide and herbicide application on cane, horticulture crops and grazing lands to determine how the different land management practices (A, B, C and D classes) affect water quality. Collected water quality data will be used to validate and calibrate the models at each scale. Annual reporting will be undertaken to assess progress towards the goals and objectives of the Reef Plan based on collected water quality data (The State of Queensland 2009).

This report outlines the first year (2009/2010 wet season) of implementation and results from paddock to sub-catchment scale water quality monitoring within the Sandy Creek catchment near Mackay in central Queensland.

# 2 METHODOLOGY

## 2.1 Site Descriptions

There are three monitoring scales from the plot (paddock) to sub-catchment scale. These include management treatment plots at the paddock scale; a multi-block scale site and a multi-farm scale site (Figure 1). There are seven treatments at the paddock scale – two treatments at the Victoria Plains site and five at the Marian site. All sites are located within the Sandy creek catchment.

### 2.1.1 Victoria Plains site

The selected block (Farm 4343A, Block 14-2; Figure 1) is located near Mt. Vince, west of Mackay ($21^o$ 11’ 3”S $148^o$ 58’ 7”E). The block has a slope of 1.1%, draining to the south. The soil has previously been mapped (1:100,000) on the change between a Victoria Plains (“Vc”) and Wollingford (“Wo”) soil (Holz and Shields 1984). A Victoria Plains soil is a uniform clay derived from quaternary alluvium, and a Wollingford soil is a soil of uplands derived from acid to volcanic rocks on 2-8% slopes.

Uniform clay soils of the alluvial plains represent 16% of the sugarcane growing area in the Mackay district, with Victoria Plains soils (Vc) occupying 7%. Soils of uplands derived from acid to intermediate volcanics on 2-8% slopes represent a further 7%, with Wollingford soils occupying 3% (Holz and Shields 1985).

The soil across the monitoring site can be generally described as a deep (>1.6 m) black to dark grey self-mulching medium clay. Prior to planting of this trial in August 2009 (when row spacing treatments were established), soybeans were grown on this block and sprayed out using glyphosate. Trash from the previous cane crop was not burnt and would have been worked into the soil. The block was divided into two treatments of 30 rows (Treatment 1; 1.5 m row spacing) and 25 rows (Treatment 2; 1.8 m row spacing, controlled traffic). Row length across the entire block ranges from approximately 225-300 m.

A brief description of the management practices undertaken in each treatment for the 2009/2010 season is given in Table 1. An attempt has also been made to identify the ABCD framework classification of each treatment. Nutrient treatments at this site were applied using side-dressed granular fertiliser. Table 2 outlines the soil management practices undertaken prior to and after sugarcane planting.

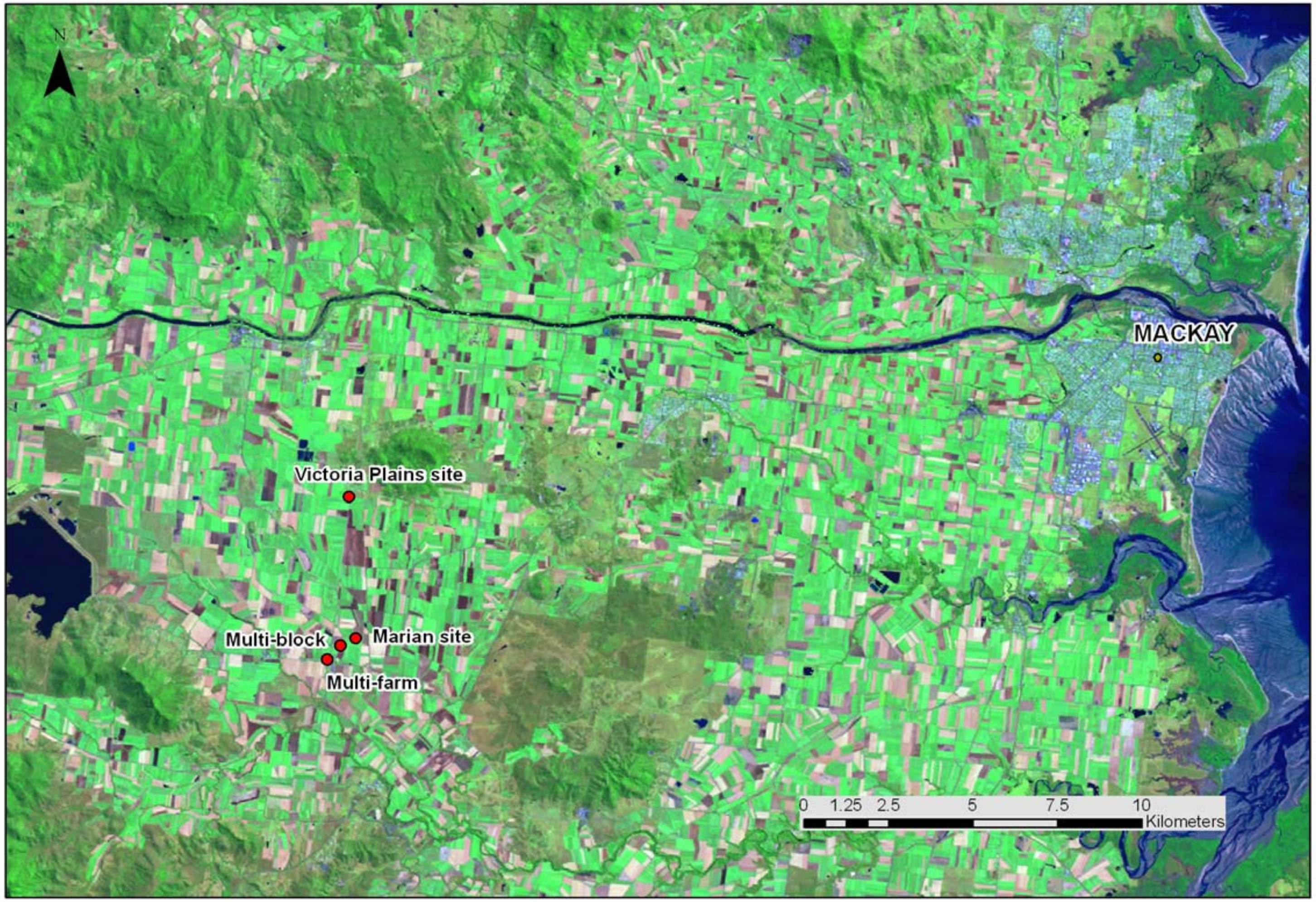

**Figure 1  Locality map of monitoring sites**

**Table 1 Application of nutrient and herbicide treatments to the Victoria Plains site**

| | ABCD Classification | Soil Management | Nutrient Management | Herbicide Management |
|---|---|---|---|---|
| Treatment 1 | CCC[1] | 1.5 m current practice | Generalised recommendation (133 kg N/ha) [2] | Residual [3] |
| Treatment 2 | BAA | 1.8 m controlled traffic | N replacement (38 kg N/ha) | Knockdown [4] |

**Table 2 Soil management practices undertaken at the Victoria Plains site**

| | Pre-plant cultivation | In-crop cultivation |
|---|---|---|
| All treatments | Offset, rip, hoe (x2) | Cutaway<br>Grubber with wings – hill-up and fill in<br>Cover – no trash blanket |

Notes:

[1] – ABCD classifications for soil/sediment, nutrients and herbicides, respectively.

[2] – Nitrogen rate applied does not take into account the contribution from the soybean crop.

[3] – Directed interspace application of Velpar K4 at 4 kg/ha (diuron at 1872 g/ha and hexazinone at 528 g/ha), Gramoxone 250 (paraquat 250g/ha) at 1 L/ha, and Baton (2, 4-d amine 560 g/ha) at 0.7 kg/ha. Blanket application of MCPA (MCPA 938 g/ha) at 1.5 L/ ha and Starane 400 (fluroxypyr 200 g/ha) at 0.5 L/ha.

[4] – Directed interspace application of Gramoxone 250 (paraquat 250 g/ha) at 1 L/ha and Baton (2, 4-d amine 560 g/ha) at 0.7 kg/ha. Blanket application of MCPA (MCPA 938 g/ha) at 1.5 L/ha and Starane 400 (fluroxypyr 200 g/ha) at 0.5 L/ha.

**Table 3 Application of nutrient and herbicide treatments to the Marian site**

| | ABCD Classification | Soil Management | Nutrient Management | Herbicide Management [5] |
|---|---|---|---|---|
| Treatment 1 | CCC[1] | 1.5 m current practice | Generalised recommendation (191 kg N/ha) | Residual [6] |
| Treatment 2 | BCC | 1.8 m controlled traffic | Generalised recommendation (191 kg N/ha) | Residual [6] |
| Treatment 3 | BBB | 1.8 m controlled traffic | Six easy steps (172 kg N/ha) | Directed knockdown [7] |
| Treatment 4 | BAA | 1.8 m controlled traffic | N replacement (97 kg N/ha) | Knockdown [8] |
| Treatment 5 | ABB | 1.8 m controlled traffic, skip row | Six easy steps (164 kg N/ha) | Knockdown [8] |

**Table 4 Soil management practices undertaken at the Marian site**

| | Pre-plant Cultivation | In-crop Cultivation |
|---|---|---|
| All treatments | Offset, rip (x2), hoe | Cutaway<br>Weeder rake<br>Grubber/multiweeder – hill-up<br>Cover – no trash blanket |

Notes:

[5] – All treatments had Amicide at 1L/ha (2,4- amicide at 625 g/ha) knockdown herbicide applied for broadleaf weed and vine control and Hero (ethoxysulfuron 150 g/ha) for nutgrass control.

[6] – Directed interspace application of Atradex 900 and Diurex 900 residual herbicides at 2.2 kg/ha each (atrazine 1980 g/ha and diuron 1980 g/ha).

[7] – Directed interspace application of Dual Gold at 1.2 kg/ha (s-metolachlor 1152 g/ha).

[8] – Helicopter applied MCPA 625 (MCPA 625 g/ha) at 1 L/ha and Starane 400 (fluroxypyr 120 g/ha) at 0.3 L/ha.

### 2.1.2 Marian site

The selected block (Farm 3120, Block 2-2; Figure 1) is located near North Eton, SW of Mackay (21° 13' 37"S 148° 58' 17"E). Slope is 0.4%, draining to the north. The soil is a duplex derived from quaternary alluvium and has been previously mapped as mapping unit "Ma1" (Marian, yellow B horizon variant) (Holz and Shields 1984), which is a Brown Chromosol (Great Soil Group) (Isbell 1996).

Duplex soils (of the alluvial plains) represent 28% of the sugarcane growing area in the Mackay district, with Marian soils (Ma and Ma1) occupying 6% (Holz and Shields 1985).

The soil across the monitoring site can be generally described as a 0.3 m deep, very dark brown (sometimes greyish) to black sandy or silty clay loam A horizon; there is a sharp change to a dark to yellowish or black medium clay B horizon with a generally strong prismatic structure. The surface of the soil is hard setting, imperfectly drained and slowly permeable.

Prior to cane being planted in August 2009 (when row spacing treatments were established), this block was in its final ratoon from a previous cane rotation which was ploughed out and replanted, with no fallow. Trash from the previous cane crop was burnt before replanting. This is not representative of current cane practice in the Mackay region with most growers choosing to undertake a fallow period or a nitrogen fixing crop rotation prior to replanting; however suitable sites were limited. The block was divided into five treatments of 18 rows each with an approximate row length of 260 m. A brief description of the management practices undertaken in each treatment is given in Table 3. An attempt has also been made to identify the ABCD framework classification of each treatment. Nutrient treatments at this site were applied using side-dressed granular fertiliser. Table 4 outlines the soil management practices undertaken prior to and after sugarcane planting.

### 2.1.3 Soil sampling and analysis

A vehicle mounted hydraulic rig was used to conduct a detailed soil characterisation of each treatment in September 2009. One soil core was collected from each paddock management treatment and soil samples were analysed by the Department of Environment and Resource Management Chemistry Centre, Brisbane. Each soil core was sampled in 10 cm increments to 1.5 m. Profile analyses at the surface and at 0.3 m intervals down the profile (or at major soil horizon changes) included 1:5 soil:water pH, electrical conductivity (EC) and chloride content ($Cl^-$); pH in calcium chloride ($CaCl_2$); particle size; cation exchange capacity (CEC), exchangeable cations; total phosphorus (P), potassium (K) and sulphur (S); moisture content at 1500 Kpa (15 bar) and $R_1$ dispersion ratio (Table 5) (Baker and Eldershaw 1993). The exchangeable cations were extracted with either ammonium chloride at ph 7.0 (aqueous) or 8.5 (alcoholic) depending on the pH of the soil (Baker and Eldershaw 1993).

A composite surface sample (0-10 cm; made up of six sub-samples) was also taken for each management treatment for nutrient analyses (Table 5). The analyses for soil fertility consisted of organic carbon (C); total nitrogen (N); bicarbonate extractable P; extractable K; trace elements of iron (Fe), manganese (Mn), zinc (Zn) and copper (Cu); sulphate-S and nitrate-N. Selected soil properties and nutrient analyses are shown in Table 6 and Table 7 and have been averaged across the treatments for each site.

**Table 5 Selected soil properties and depths analysed**

| **Soil Test** | **Sample Type and Depth (cm)** | | | | | | |
|---|---|---|---|---|---|---|---|
| | $B_{10}$[1] | $P_{0-10}$[2] | $P_{20-30}$ | $P_{50-60}$ | $P_{80-90}$ | $P_{110-120}$ | $P_{140-150}$ |
| pH, EC, $Cl^-$ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Cations/CEC/ESP | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Total P, K, S, | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Total N, Total C | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| TOC, TKN, $NO_3$-N | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Acid P, Bic P, repl K | ✓ | | | | | | |
| B, Cu, Zn, Mn, Fe | ✓ | | | | | | |
| Ca, Mg, Na, K | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| % ADM | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Particle Size Analysis | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| 15 bar moisture | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Dispersion ratio $R_1$ | | ✓ | ✓ | ✓ | ✓ | | |

Note:

[1] – B = bulked sub-sample (0-10 cm) taken from six locations across the treatment

[2] – P = soil profile sample sub-sampled into the depth increments indicated

**Table 6 Selected soil properties at different depths for the Victoria Plains site**
(Note: Data averaged across the two treatments)

| Depth | pH | EC (dS/m) | Coarse Sand (%) | Fine Sand (%) | Silt (%) | Clay (%) | CEC (meq/100g) | Nitrate-N (mg/kg) $NO_3$-N | Phosphorus (mg/kg) P bicarb Colwell* | Total Organic Carbon (%) | $Cl^-$ (mg/kg) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-0.1m | 5.85 | 0.14 | 5.0 | 23.5 | 24.0 | 50.5 | 40.5 | 37.0 | 20 | 2.56 | 47.5 |
| 0.2-0.3m | 6.05 | 0.08 | 4.5 | 24.0 | 24.5 | 53.0 | 41.5 | 21.5 |  | 1.99 | 25.0 |
| 0.5-0.6m | 6.95 | 0.07 | 4.5 | 20.5 | 21.5 | 57.5 | 43.0 | 6.0 |  | 1.32 | 25.0 |
| 0.8-0.9m | 7.80 | 0.07 | 3.5 | 20.5 | 20.0 | 60.5 | 44.5 | 1.75 |  | 0.87 | 33.5 |
| 1.1-1.2m | 8.40 | 0.27 | 5.0 | 18.5 | 20.5 | 59.5 | 43.5 | 1.0 |  | 0.60 | 43.5 |
| 1.4-1.5m | 8.50 | 0.26 | 6.5 | 17.0 | 21.0 | 58.5 | 39.0 | <1 |  | 0.35 | 61.5 |

* Surface Bulk

**Table 7 Selected soil properties at different depths for the Marian site**
(Note: Data averaged across the five treatments)

| Depth | pH | EC (dS/m) | Coarse Sand (%) | Fine Sand (%) | Silt (%) | Clay (%) | CEC (meq/100g) | Nitrate-N (mg/kg) $NO_3$-N | Phosphorus (mg/kg) P bicarb Colwell* | Total Organic Carbon (%) | $Cl^-$ (mg/kg) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-0.1m | 6.70 | 0.13 | 27.2 | 42.4 | 14.4 | 19.6 | 12.2 | 13.2 | 95 | 1.35 | 83.8 |
| 0.2-0.3m | 6.88 | 0.09 | 28.4 | 38.8 | 12.0 | 24.2 | 10.0 | 5.3 |  | 0.86 | 47.2 |
| 0.5-0.6m | 7.74 | 0.12 | 25.8 | 32.8 | 7.2 | 37.8 | 13.8 | <1 |  | 0.34 | 43.2 |
| 0.8-0.9m | 7.90 | 0.14 | 23.0 | 40.0 | 7.0 | 34.0 | 13.4 | <1 |  | 0.20 | 56.0 |
| 1.1-1.2m | 7.94 | 0.12 | 22.6 | 35.6 | 10.2 | 34.6 | 15.4 | <1 |  | 0.13 | 65.8 |
| 1.4-1.5m | 8.02 | 0.12 | 22.4 | 35.8 | 14.8 | 30.2 | 15.0 | <1 |  | <0.15 | 71.0 |

* Surface Bulk

### 2.1.4 Rainfall, runoff and water quality

Each treatment monitoring site is controlled using a Campbell Scientific CR800 data logger housed in a weatherproof container. The logger is programmed to read all sensors every 60 seconds. When runoff water begins to flow through the San Dimas flumes (see following), the station will begin the pre-programmed sampling routine.

Rainfall is measured at each site using a Hydrological Services TB4 tipping bucket rain gauge, with 0.2 mm bucket. Bucket tips are recorded by the data logger allowing for measurements of rainfall volume and intensity. A manual rain gauge was installed at each site as a backup, but these overtopped during large rainfall events.

San Dimas flumes (300 mm; Figure 2) are used to measure the runoff discharge from each treatment. The galvanised steel flumes were manufactured to standard specifications as outlined by Walkowiak (2006). The flumes are installed approximately 5 m beyond the end of the sugarcane rows (outside of the actual cropped area), and rubber belting is used as bunding to collect runoff from four inter-rows (commencing eight rows in from the edge of the treatment) and direct the runoff water into the flume for discharge measurement and sample collection. The standard discharge calibration equation (Walkowiak 2006) for converting water depth into discharge is:

$$Q\ (\mathrm{L/s}) = 0.110925 \times \mathrm{depth}\ (\mathrm{mm})^{1.285788}$$

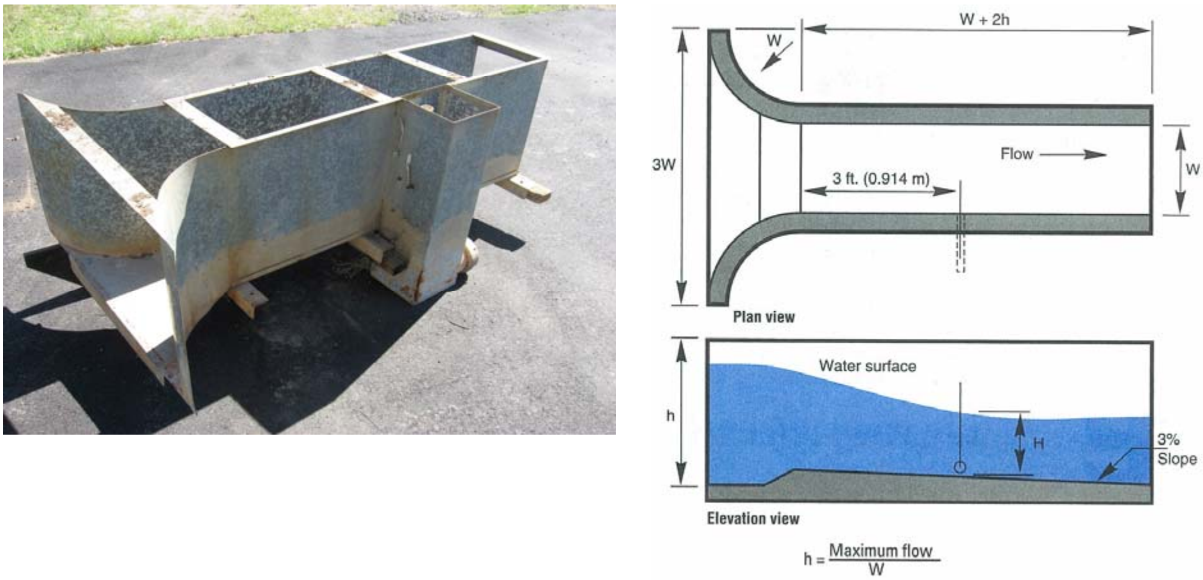

Figure 2 A 300 mm San Dimas flume (left) and critical design dimensions (right)

Water depth is measured using a Campbell Scientific CS450 stainless steel SDI-12 pressure transducer installed in a stilling well at the side of the San Dimas flume with a connection to the main chamber. The pressure transducer has an accuracy of approximately 0.1% at full scale. Standard equations programmed into the logger automatically convert pressure into water height.

Event integrated water samples are collected using an Isco Avalanche refrigerated auto-sampler containing four 1.8 L glass bottles. The refrigeration system is activated after collection of the first sample. The sampler is triggered by the CR800 logger. Using the flume discharge equation above, the logger is programmed to take a sub-sample (~160 mL) for every 3 mm of runoff, filling each bottle consecutively and allowing for 120 mm of runoff to be sampled. The bulked samples are sub-sampled and analysed for total suspended solids (TSS; Section 2.4.1), nutrients (total and filtered; Section 2.4.3), and herbicides (Section 2.4.4) where possible (depending on volume collected). Following smaller rainfall events with limited volume of sample collected, priority is given to analysis in the order of nutrients, herbicides and then TSS.

A radio telemetry network was established between sites that are “within line of sight” (e.g. paddock sites on the Marian soil, Multi-block (Section 2.2) and Multi-farm (Section 2.3) scale sites). Next G modems were located at the Multi-block site and treatment two of the Victorian Plains site to enable communication and download/upload of information from offsite.

Separate power supply systems were installed for the data logger and instrumentation, and for the auto-sampler. The logger power and charging system consists of an 18 A/hr deep cycle battery, a 10 W solar panel with a power regulator, while the auto-sampler power system is two 100 A/hr sealed, deep cycle batteries, a 40 W solar panel and a power regulator.

### 2.1.5 Soil moisture

Continuous soil moisture monitoring (data not reported) is undertaken directly below the stool within treatments that were expected to have different runoff/infiltration (Treatments 1, 2 and 5 on the Marian soil, and both treatments on the Victoria Plains soil). Moisture content is recorded at one hourly intervals (using EnviroSCAN systems) and logged using the CR800 data loggers. Six sensors are used at each monitoring site, distributed at 20 cm intervals to 1 m, with the final sensor at 1.5 m.

EnviroSCAN sensors consist of two brass rings (50.5 mm diameter and 25 mm high) mounted on a plastic body and separated by a 12 mm plastic ring. The sensors are designed to operate inside a PVC access tube. The frequency of oscillation depends on the permittivity of the media surrounding the tube. Sensitivity studies show that 90% of the sensor’s response is obtained from a zone that stretches from about 3 cm above and below the centre of the plastic ring to about 3 cm in radial direction, starting from the access tube (Kelleners *et al.* 2004).

### 2.1.6 Drainage

Drainage water quality below the rooting depth was measured on two occasions following rainfall events at the end of January and mid February using soil solution samplers (“suction cups”). Two soil solution samplers were installed in each treatment (in close proximity to the subsurface EnviroSCAN’s,) at a depth of 0.9 m. A soil solution sampler in Marian soil Treatment 5 was destroyed during soil preparation prior to any sampling taking place and was not replaced. Samples are bulked from each treatment, and analysed for nutrients (total and filtered) and herbicides. Only herbicide results are reported.

### 2.1.7 Agronomic sampling

Events, such as farm operations (including tillage, nutrient and pesticide applications) that change ground cover and growth stages of the crop (including date of emergence, canopy closure, crop destruction) are recorded in a comprehensive field diary. Table 8 outlines the major events experienced by most crops along with specific information that will be recorded. The date of the event and any relevant information has also been captured.

**Table 8 Example of information recorded in event diary**

| Event | Specific information | | | |
|---|---|---|---|---|
| Crop start | Date of planting | Date of ratooning | | |
| Irrigation | Amount applied | Application method | Quality of incoming water | |
| Nutrition | Product used | Nutrient analysis | Amount applied | Placement |
| Pesticide | Product used | Active ingredient | Amount applied | Placement |
| Cultivation | Type of operation | Depth of cultivation | Zone cultivated | % of residue incorporated |
| Harvest | Date | Method used | | |

#### *2.1.7.1 Cane height*

Cane heights were measured on a regular basis from 16 weeks (mid December) after planting until cane began to flower in April (data not reported). Ten cane stalks were randomly selected from each treatment and flagged for identification over the period of data acquisition. Stalks were measured using an extendible PVC pole with height increments marked. Following the strong winds of cyclone Ului in March, cane became increasingly difficult to measure and results likely contained greater error due to the bent cane stalks. Growth was recorded concurrently using digital photography.

#### *2.1.7.2 Yield measurements*

Two methods were undertaken to determine any yield differences between treatments at each site and to identify any yield differences within treatments. Initially a two row by five metre length block of cane was hand cut from the northern and southern ends of both sites. To reduce any effects of increased weather exposure at plot edges all samples were cut at least 10 m into the cane block. All cane stalks (with leaves and top removed) were weighed using a Ruddweigh livestock scale and replaced in the block for inclusion during mechanical harvesting. Cane was mechanically harvested in mid September at the Victoria Plains site and late October at the Marian site. All bin numbers were recorded and treatments remained in separate bins to allow for yield and PRS (percent recoverable sugar) measurements to be collected for each treatment during cane processing. No attempt was made to measure the nitrogen removed in the harvested cane.

### 2.1.8 Planting, nutrient and herbicide application

#### *2.1.8.1 Victoria Plains*

Cane (Q208) was planted on both treatments on August 2nd, and nutrients applied as a surface application of 210 kg/ha Diammonium Phosphate (38 kg N/ha, 42 kg P/ha and 4 kg S/ha) fertiliser at planting as a planting mix. Further application of nutrients on the high N treatment (Treatment 1) occurred on October 6th in the form of 207 kg/ha Urea (95 kg N/ha). All residual and knockdown herbicides were applied via an interspace-directed spray in mid January ("out-of-hand" stage), except the vine control herbicides MCPA and Starane 400 which were applied via a boom spray on the same day (Table 1).

### *2.1.8.2 Marian*

All treatments were planted (Q208) on August 15th, and nutrients applied as a surface application planting mix of 250 kg/ha Diammonium Phosphate (45 kg N/ha, 50 kg P/ha and 5 kg S/ha) on the same day. Nutrient treatments were then applied on October 15th (to make up the nitrogen rates shown in Table 3) as a side-dressed application beside the cane stool. All residual and knockdown herbicides were applied via an interspace-directed spray in late October, except the vine control herbicides MCPA and Starane 400 which were applied via a boom spray on the same day, or later in the season by helicopter (Table 3). Table 4 outlines the soil management practices undertaken prior to and after sugarcane planting.

## 2.2 Multi-block scale

At the Multi-block scale (21$^o$ 13' 36"S 148$^o$ 57' 57"E; Figure 1), runoff is measured within a farm drain (catchment area approximately 53.5 ha) using a 1 in 40 flat vee crest weir, with depth of flow again being recorded by a pressure transducer at one minute intervals.

The standard discharge calibration equation (Cooney *et al.* 1992) for converting water depth into discharge is:

| **Water Depth (m)** | **Discharge equation** | **Notes** |
|---|---|---|
| 0 – 0.125 m | Q (cumecs) = 1.557 x 40 x depth (m)$^{2.5}$ | Within vee |
| 0.126 – 0.250 m | Q (cumecs) = 1.557 x 40 x [depth$^{2.5}$ – (depth – 0.125)$^{2.5}$] | Within wing walls |
| 0.251 – 0.350 m | Subject to final installation | Within drain |

As with the paddock sites, rainfall (amount and intensity) is measured using a Hydrological Services TB4 tipping bucket rain gauge. A Campbell Scientific CR800 data logger collects outputs from sensors and triggers the Isco Avalanche refrigerated auto-sampler (with four 1.8 L glass bottle configuration). While submerged, an Analite NEP9510 turbidity probe continuously measures turbidity (data not reported), and water depth is measured via a Campbell Scientific CS450 SDI-12 pressure transducer to calculate flow.

Using the weir discharge equations above, an attempt was made to program the logger to sub-sample (~160 mL) every 3 mm of runoff through the weir. Where possible during large flow events, glass bottles were replaced to allow for sampling over a larger part of the hydrograph. At present, the accuracy of flow calculations is uncertain as water would back-up in the channel after a downstream storage dam filled affecting flow rates over the weir. Additionally, as the channel overtopped water spread out across the paddocks and measuring water heights and flow rates became somewhat problematic. Again bulked samples were analysed (Section 2.4) for nutrients (total and filtered), herbicides and TSS, with priority being given to nutrients, then herbicides depending on the volume of sample collected.

## 2.3 Multi-farm scale

At the Multi-farm scale ($21^{o}$ 13’ 49”S $148^{o}$ 57’ 45”E; Figure 1), runoff is measured within a natural drain (catchment area approximately 2965 ha) using a 1 in 20 flat vee crest weir, with depth of flow again being recorded by a pressure transducer at one minute intervals. With the exception of the weir, sampling equipment at the Multi-farm scale is identical to that of the Multi-block scale.

The standard discharge calibration equation (Cooney *et al.* 1992) for converting water depth into discharge is:

| **Water Depth (m)** | **Discharge equation** | **Notes** |
|---|---|---|
| 0 - 0.250 m | Q (cumecs) = 1.557 x 20 x $\text{depth}^{2.5}$ | Within vee |
| 0.251 – 0.500 m | Q (cumecs) = 1.557 x 20 x [$\text{depth}^{2.5}$ – $(\text{depth} – 0.250)^{2.5}$] | Within wing walls |
| 0.501 – 0.675 m | Subject to final installation | Within drain |

Using the weir discharge equation above, the logger was programmed to sub-sample (~160 mL) every 3 mm of runoff allowing for a total of 120 mm of runoff to be sampled. Where possible during large flow events, glass bottles were replaced to allow for sampling over a larger part of the hydrograph. Accurate flow rates could not be gauged when water overtopped the channel and spread out over the surrounding area. The bulked sample were sub-sampled and analysed for nutrients (total and filtered), herbicides and sediments (Section 2.4).

## 2.4 Laboratory methodologies

Analysis of total suspended solids, turbidity, electrical conductivity, and nutrients (filtered and unfiltered) are conducted by the Australian Centre for Tropical Freshwater Research (ACTFR) laboratory, James Cook University, Townsville. Herbicide samples are analysed by the Queensland Health Forensic and Scientific Services laboratory, Brisbane. Both laboratories hold appropriate NATA accreditation.

### 2.4.1 Total suspended solids and turbidity

To determine the mass per volume of total suspended solids (TSS), a known volume of sample is filtered through a pre-weighed standard glass fibre filter. The filter is then oven dried at between 103 to 105 $^{o}$C in 1-hour time intervals and the difference in weight is determined between the initial filter weight and the filter and sample weight. The sample is dried until this difference becomes constant or weight change is less than 4% of previous weight change or less than 0.5 mg, whichever is less (APHA 1998).

Laboratory turbidity measurements (APHA 2130B) are based on a comparison between the intensity of light scattered by the water sample under defined conditions, and the intensity of light scattered by a standard reference suspension under the same defined conditions. A formazin polymer is used as the primary standard reference suspension (turbidity of 4000 NTU).

### 2.4.2 Electrical conductivity

Electrical conductivity is measured directly using an appropriately calibrated conductivity cell rinsed with sample at a known temperature. The conductivity cell is calibrated with known standards of potassium chloride solution prior to analysis (APHA 1998).

### 2.4.3 Nutrients

Samples are analysed for ammonia, total filterable nitrogen and phosphorus, filterable reactive phosphorus (FRP), nitrogen oxides ($NO_x$), particulate N and P, dissolved organic nitrogen and phosphorus, and total kjeldahl nitrogen and phosphorus. Brief analysis methodologies are provided here for those nutrient forms that are reported on in this document. More detailed laboratory methodologies and those for nutrient species analysed for, but not reported here, can be found elsewhere (APHA 1998).

#### *2.4.3.1 Nitrogen species*

Ammonia levels are measured from the filtered samples using the automated phenate method and a continuous flow analytical instrument. The ammonia in the sample reacts with alkaline phenol and hypochlorite to form indophenol blue, the quantity formed being proportional to the amount of ammonia. Results are determined by comparing the intensity of the indophenol following the reaction of the sample with standard curves determined from known ammonia standards. Total kjeldahl nitrogen is a combination of organic nitrogen and ammonia, and were again determined using the automated phenate method following kjeldahl digestion.

Nitrogen oxides are detected in samples using the automated cadmium reduction method and a continuous flow analytical instrument (APHA 1998). Nitrate is reduced to nitrite in the presence of cadmium and the concentration of $NO_2^-$ determined using a reactive dye. The resulting colour is compared to standard curves. All particulate concentrations are calculated by subtracting the filtered nutrients from the total nutrients of that species. Only $NO_x$ results are reported.

#### *2.4.3.2 Phosphorus species*

Reactive phosphorus species are those that respond to calorimetric testing without requiring preliminary hydrolysis or oxidative digestion and consist almost entirely of orthophosphates. Concentrations of FRP are determined using the automated ascorbic acid reduction method. The phosphorus present in the sample is separated by filtering through a 0.45 µm filter. The orthophosphate in the sample is converted to an antimony-phosphomolybdate complex by reacting with ammonium molybdite and potassium antimonyl and then reducing using ascorbic acid to produce a blue solution. The concentration of FRP is then determined using colorimetry (APHA 1998). Only FRP results are reported.

### 2.4.4 Herbicides

All water samples from all sites were analysed for a standard suite of 14 herbicides using liquid chromatography mass spectrometry. Herbicides analysed for included ametryn, atrazine, desethyl atrazine, desisopropyl atrazine, diuron, fluometuron, hexazinone, prometryn, simazine, tebuthiuron, bromacil, metolachlor, terbutryn and imidacloprid. While not all herbicides were expected to be found at these sites, this is a standard analysis procedure.

# 3 RESULTS

## 3.1 Overview of events

### 3.1.1 Paddock scale

Fifteen rainfall events causing paddock runoff occurred in the 2009/10 wet season at the Victoria Plains site and 13 at the Marian site. A rainfall and runoff event was defined as rainfall that caused enough runoff for samples to be collected (>3 mm of runoff). Not all treatments ran off for each event. As expected more rainfall was required to produce a runoff event at the beginning of the wet season than later in the wet season when the soil moisture had significantly increased. The first distinct rainfall event causing runoff occurred on January 25th 2010 and the final one was Cyclone Ului which hit the Mackay region on March 21st 2010 (samplers were removed for safekeeping prior to this event and consequently no water quality samples were collected).

Irrigation was applied to the Marian site on 10 occasions via a centre pivot at a rate of approximately 40 mm per application. Early applications ranged from August 2009 until the end of December and were prior to any runoff events occurring. Later applications were in July and August 2010. The Victoria Plains site had a total of 115 mm of irrigation applied via a spray line in mid August and mid October, again prior to any site runoff. No runoff was generated from any irrigation.

### 3.1.2 Multi-block and Multi-farm scale

At the Multi-block and Multi-farm scales a rainfall and runoff event was again one that caused the Isco samplers to collect at least one water sample. Theoretically this should have been 3 mm of runoff for each site. As previously discussed however, there were significant issues relating to accurately measuring flow rates over the weirs which consequently impacted on the estimated catchment runoff rates. Both sites generally had a longer period of lag time between rainfall and flow than the paddock scale and they also tended to sample for a longer period. For approximately four weeks from late February until late March, the Multi-farm drain flowed continuously and it was difficult to define an event. Between December 1st 2009 and March 31st 2010, 1638 mm of rainfall was recorded at the Multi-block site while rainfall records from the Multi-farm site are incomplete due to equipment malfunctions. The Multi-farm catchment had nine distinct runoff events and the Multi-block catchment had seven events recorded, with the first runoff event occurring on December 27th 2009.

## 3.2 Victoria Plains site

### 3.2.1 Rainfall and runoff

A total of 1636 mm of rainfall was recorded at the Victoria Plains site between December 1st 2009 and March 31st 2010, with the highest daily rainfall of 206.2 mm occurring on January 31st.

**Table 9 Event rainfall and runoff at the Victoria Plains site during the 2009/10 wet season**

| Event | Start of Runoff | End of Runoff | Rainfall Total (mm) | Treatment 1 Runoff | Treatment 2 Runoff |
|---|---|---|---|---|---|
| 1 | 25/01/2010 0:00 | 26/01/2010 9:00 | 152.4 | 77.0 | 51.3 |
| 2 | 26/01/2010 9:00 | 26/01/2010 14:00 | 56.4 | 12.2 | 10.9 |
| 3 | 30/01/2010 12:00 | 31/01/2010 18:00 | 209.4 | 142.0 | 97.3 |
| 4 | 9/02/2010 16:00 | 10/02/2010 7:00 | 69.6 | 21.8 | 21.1 |
| 5 | 10/02/2010 9:00 | 12/02/2010 8:00 | 51.6 | 46.3 | 15.4 |
| 6 | 16/02/2010 12:00 | 17/02/2010 9:00 | 34.4 | 22.3 | 14.6 |
| 7 | 17/02/2010 0:00 | 18/02/2010 9:00 | 97.4 | 79.6 | 82.6 |
| 8 | 18/02/2010 9:00 | 18/02/2010 21:00 | 8.2 | 5.1 | 6.0 |
| 9 | 20/02/2010 0:00 | 20/02/2010 9:00 | 13.2 | 4.5 | 4.7 |
| 10 | 20/02/2010 9:00 | 22/02/2010 9:00 | 96.8 | 59.1 | 57.1 |
| 11 | 25/02/2010 0:00 | 27/02/2010 7:00 | 97.0 | 55.8 | 39.0 |
| 12 | 27/02/2010 7:00 | 1/03/2010 0:00 | 127.8 | 98.9 | 80.5 |
| 13 | 20/03/2010 18:00 | 21/03/2010 12:00 | 161.4 | 126.3 | 118.2 |
| 14 | 22/03/2010 0:00 | 22/03/2010 12:00 | 39.0 | 26.7 | 27.6 |
| 15 | 22/03/2010 12:00 | 23/03/2010 0:00 | 53.6 | 32.2 | 39.0 |
| **Total** | | | **1268.2** | **809.8** | **665.3** |

At the Victoria Plains site, total runoff (Table 9; Figure 3) from individual runoff events from Treatment 2 (1.8 m row spacing) averaged 18% less than Treatment 1 (1.5 m row spacing) (665 mm and 810 mm, respectively). Runoff from Treatment 2 was delayed by ~6 minutes on average compared with Treatment 1, and the peak runoff rate was ~2% lower, all contributing to reduced runoff.

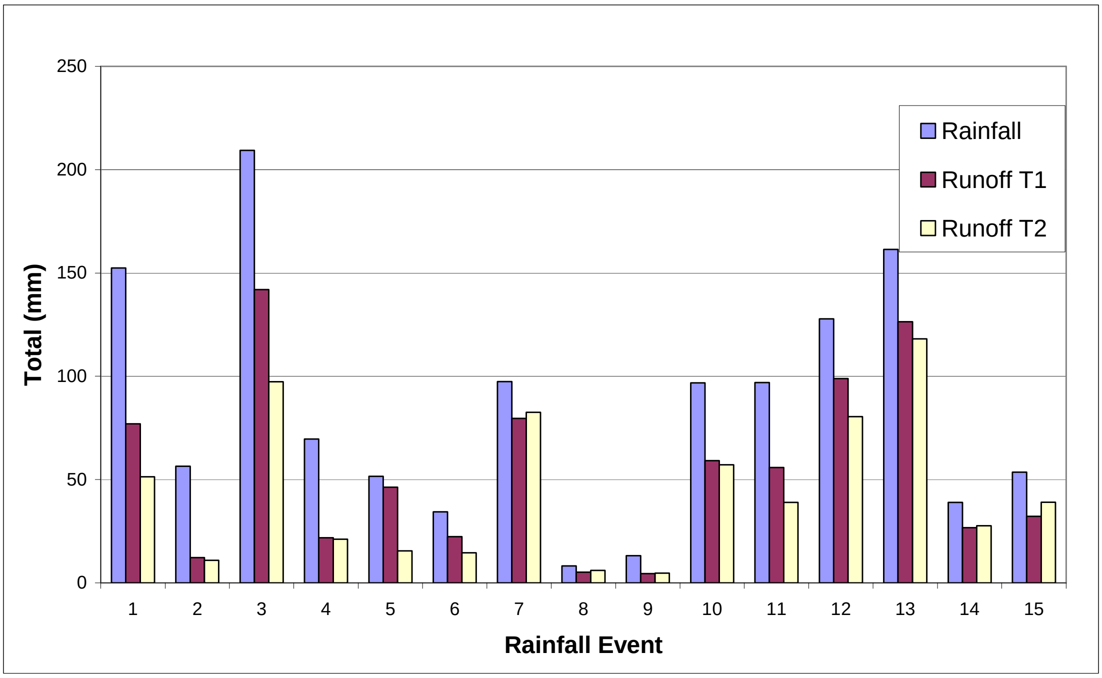

**Figure 3 Rainfall and runoff for the Victoria Plains site treatments in the 2009/10 wet season**
(Note: First runoff event was 176 days after cane planting)

### 3.2.2 Total suspended solids, turbidity and electrical conductivity

Levels of TSS varied considerably across the samples and across both treatments revealing no obvious seasonal trends (Figure 4), but increasing peak runoff rates tended to produce higher TSS concentrations ($R^2$=0.33 with one runoff event excluded, data not shown). Total suspended solid concentrations ranged from 97-3000 mg/L in Treatment 1, with these results recorded four days apart. Generally for this treatment, TSS levels remained between 100 mg/L and 1000 mg/L with a mean for the wet season of 826 mg/L and a median of 495 mg/L. Treatment 2 TSS concentrations ranged from 35-1200 mg/L but had higher concentrations than Treatment 1 for the first two and the final two runoff events of the season. On the day that Treatment 1 had its highest recorded TSS concentration (3000 mg/L), Treatment 2 recorded its lowest TSS concentration for the season (35 mg/L). Treatment 2 had a mean TSS concentration of 631 mg/L and a median of 740 mg/L. Total loads are presented in Section 3.2.4.

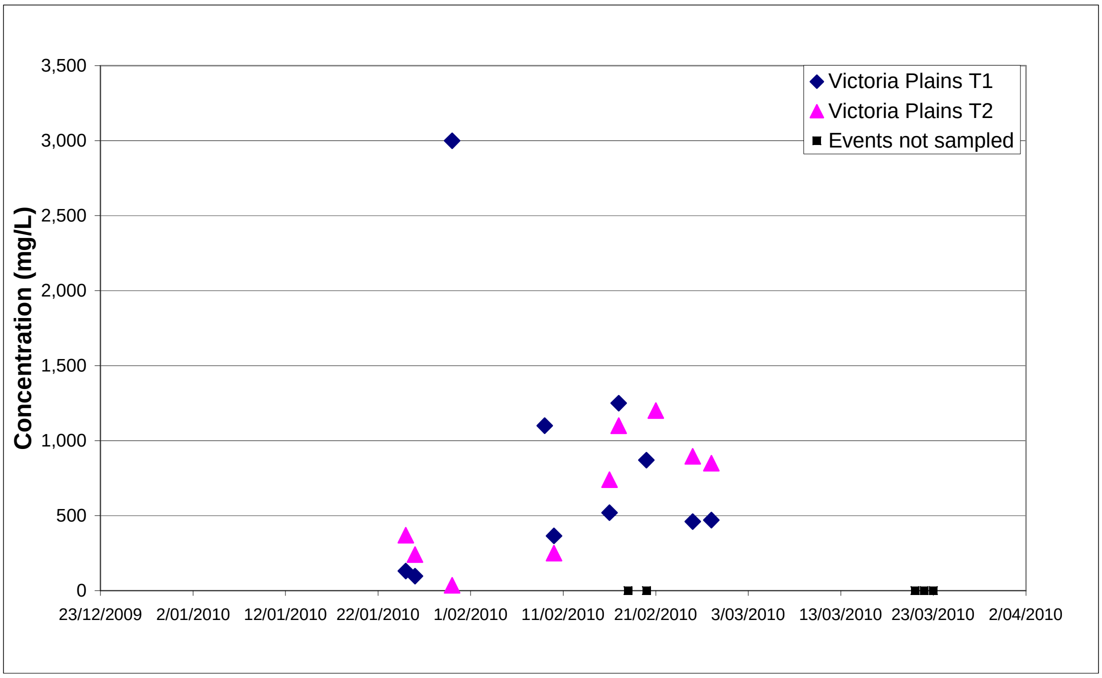

**Figure 4 TSS concentrations measured in runoff from the Victoria Plains site**

Runoff turbidity showed no obvious patterns between treatments and throughout the wet season. Treatment 1 turbidity ranged from 150-2400 NTU, with an average of 988 NTU and a median of 805 NTU. Turbidity from Treatment 2 ranged from 60-1300 NTU with an average of 784 NTU and median of 900 NTU. When samples from each treatment were combined, there was a good relationship ($R^2$=0.90) between TSS concentration and turbidity (Figure 5).

There was little variation in electrical conductivity (EC) between the two treatments with Treatment 1 ranging from 47-260 µS/cm and Treatment 2 from 62–150 µS/cm. Samples from Treatment 1 had slightly higher EC values for the first two runoff events and slightly lower for the last three runoff events.

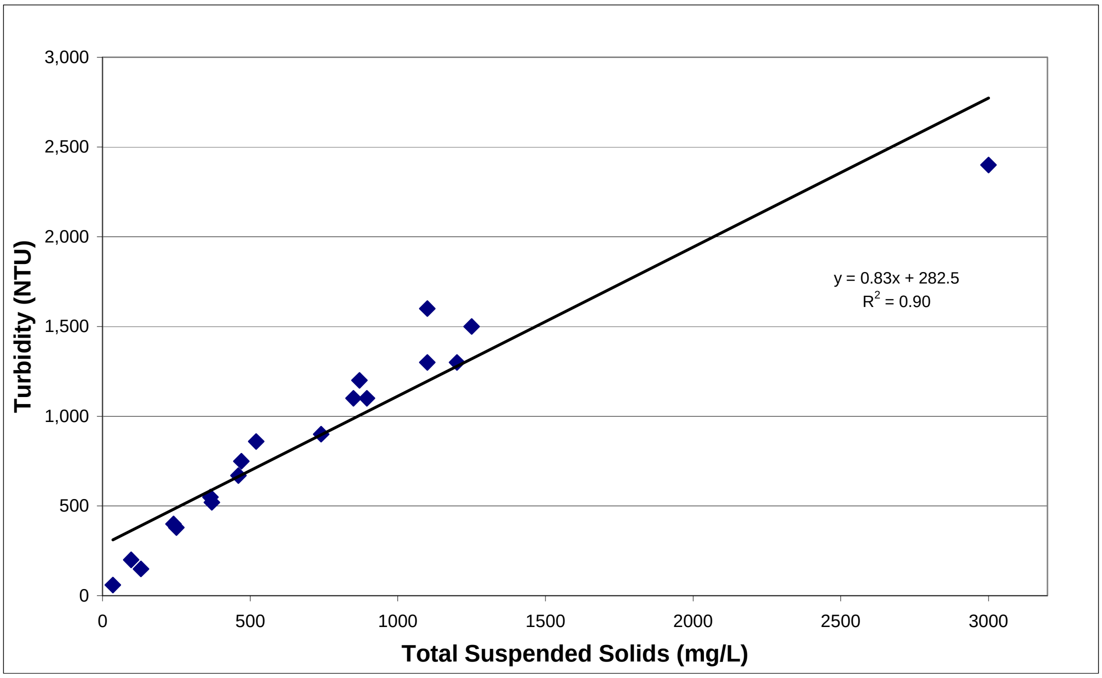

**Figure 5 Relationship between TSS concentrations and turbidity at the Victoria Plains site**

### 3.2.3 Nutrients

#### *3.2.3.1 Nitrogen oxides*

Nitrogen containing fertilisers were applied in early August 2009. The first runoff event occurred at this site in late January 2010, 176 days after nutrient application.

Treatment 1 (high N application) $NO_x$ concentrations ranged from 13,626 µg N/L in the first runoff event to 58 µg N/L in the final event (Figure 6). The mean and median $NO_x$ concentrations recorded were 905 µg N/L and 204 µg N/L respectively. Treatment 2 concentrations ranged between 4604 µg N/L in the first runoff event and 191 µg N/L in latter events, with a mean of 1087 µg N/L and a median of 473 µg N/L. The first runoff event produced $NO_x$ concentrations in runoff approximately one-third that of Treatment 1. Higher $NO_x$ concentrations were recorded in runoff from Treatment 1 for the first four runoff events with the differences reducing for each event, following this Treatment 2 consistently recorded slightly higher $NO_x$ concentrations.

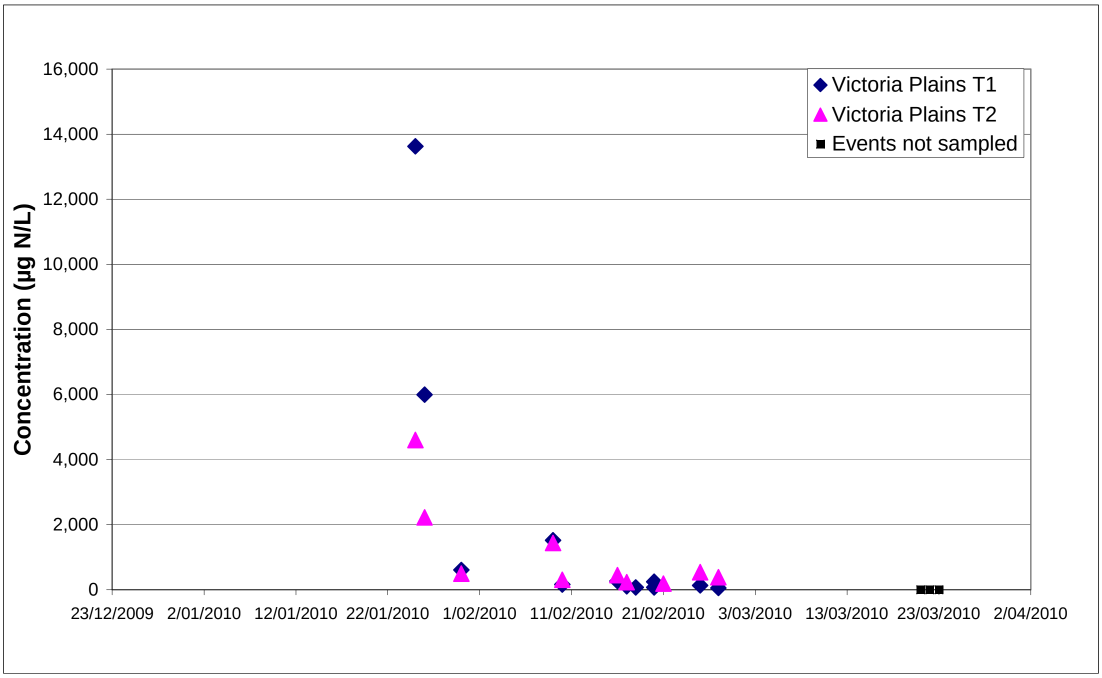

**Figure 6 $NO_x$ concentrations in runoff from the Victoria Plains treatments**
(Note: log plot of this graph is contained in Section 7.1)

#### *3.2.3.2 Filterable reactive phosphorus*

Phosphorus was applied to both treatments at equal rates resulting in similar concentrations being detected in runoff. Concentrations recorded in runoff from Treatment 1 ranged between 64 and 18 µg P/L and 66 to 21 µg P/L from Treatment 2. Treatment 1 recorded an average of 34 µg P/L and a median of 30 µg P/L, while Treatment 2 recorded an average of 31 µg P/L and a median of 28 µg P/L. Both treatments showed a general reduction in FRP lost in runoff as the wet season progressed.

### 3.2.4 Loads

A regression curve was fitted to known nutrient concentrations with time after the first runoff event to estimate events that had runoff on only one of the two treatments or when samplers were removed prior to the cyclone in March (Table 10). Nutrient, herbicide and sediment loads were calculated by converting discharges through flumes to millimetres of runoff for each runoff event and using known plot areas and analysed concentrations from collected water samples or values from regression curves (Table 11).

**Table 10 Regression curves for nutrient concentrations, Victoria Plains site**

| | Regression Equation | | $R^2$ value | |
|---|---|---|---|---|
| | T1 | T2 | T1 | T2 |
| $NO_x$ | $y=3095x^{-0.9278}$ | $y=1745.5x^{-0.472}$ | 0.80 | 0.71 |
| FRP | $y=54.31e^{-0.0305x}$ | $y=59.503e^{-0.0314x}$ | 0.63 | 0.52 |

(Note: x = days since first runoff event. First two runoff points for T2 FRP ignored in regression curves)

**Table 11 Calculated loads from runoff on the Victoria Plains treatments**

| **Event No** | **Date and Time** | **$NO_x$ (kg/ha)** | | **FRP (kg/ha)** | | **Sediment (kg/ha)** | |
|---|---|---|---|---|---|---|---|
| | | **T1** | **T2** | **T1** | **T2** | **T1** | **T2** |
| 1 | 25/01/2010 0:00 to 26/01/2010 9:00 | 10.5 | 2.36 | 0.049 | 0.013 | 100 | 190 |
| 2 | 26/01/2010 9:00 to 26/01/2010 14:00 | 0.733 | 0.242 | 0.007 | 0.003 | 11.8 | 26.2 |
| 3 | 30/01/2010 12:00 to 31/01/2010 18:00 | 0.863 | 0.481 | 0.048 | 0.076 | 4260 | 34.1 |
| 4 | 9/02/2010 16:00 to 10/02/2010 7:00 | 0.332 | 0.304 | 0.006 | 0.008 | 2340 | |
| 5 | 10/02/2010 9:00 to 12/02/2010 8:00 | 0.075 | 0.047 | 0.024 | 0.004 | 169 | 38.6 |
| 6 | 16/02/2010 12:00 to 17/02/2010 9:00 | 0.059 | 0.066 | 0.006 | 0.006 | 116 | 108 |
| 7 | 17/02/2010 0:00 to 18/02/2010 9:00 | 0.084 | 0.192 | 0.014 | 0.031 | 995 | 909 |
| 8 | 18/02/2010 9:00 to 18/02/2010 21:00 | 0.004 | 0.023 | 0.002 | 0.002 | | |
| 9 | 20/02/2010 0:00 to 20/02/2010 9:00 | 0.011 | 0.018 | 0.001 | 0.001 | | |
| 10 | 20/02/2010 9:00 to 22/02/2010 9:00 | 0.043 | 0.109 | 0.010 | 0.012 | 515 | 685 |
| 11 | 25/02/2010 0:00 to 27/02/2010 7:00 | 0.076 | 0.210 | 0.013 | 0.011 | 257 | 349 |
| 12 | 27/02/2010 7:00 to 1/03/2010 0:00 | 0.057 | 0.311 | 0.021 | 0.021 | 465 | 684 |
| 13 | 20/03/2010 18:00 to 21/03/2010 12:00 | 0.090 | 0.312 | 0.013 | 0.013 | | |
| 14 | 22/03/2010 0:00 to 22/03/2010 12:00 | 0.020 | 0.072 | 0.003 | 0.003 | | |
| 15 | 22/03/2010 12:00 to 23/03/2010 0:00 | 0.023 | 0.101 | 0.003 | 0.004 | | |
| **Total** | | **13.0** | **4.85** | **0.220** | **0.208** | **>10,000** | **>3,000** |

(Note that red figures indicate loads estimated from regression curves where samples were not collected. A total sediment load could not be determined due to some runoff events not being sampled)

## 3.2.5 Surface herbicides

Herbicide runoff samples were first collected from the Victoria Plains site only eight days after application.

### *3.2.5.1 Treatment 1*

A total of eight (event integrated) runoff herbicide samples were collected from Treatment 1 in the 2009/2010 wet season. Diuron and hexazinone (applied this season) were detected in all samples and concentrations decreased exponentially with time over the two month sampling period ($R^2$ values of 0.78 and 0.87 respectively) (Figure 7 and Figure 8). Based on these equations, the runoff-available half-lives of diuron and hexazinone are 13 and five days, respectively. Trace concentrations of atrazine (Figure 9) and its breakdown products (desethyl atrazine and desisopropyl atrazine) were also detected. Given the low levels of atrazine (1.1 µg/L or less) and its breakdown products (<0.2 µg/L) and that only the residual herbicide Velpar K4 (diuron 468 g/kg and hexazinone 132 g/kg) was applied for weed control, it is assumed that any detected atrazine was residual from previous applications.

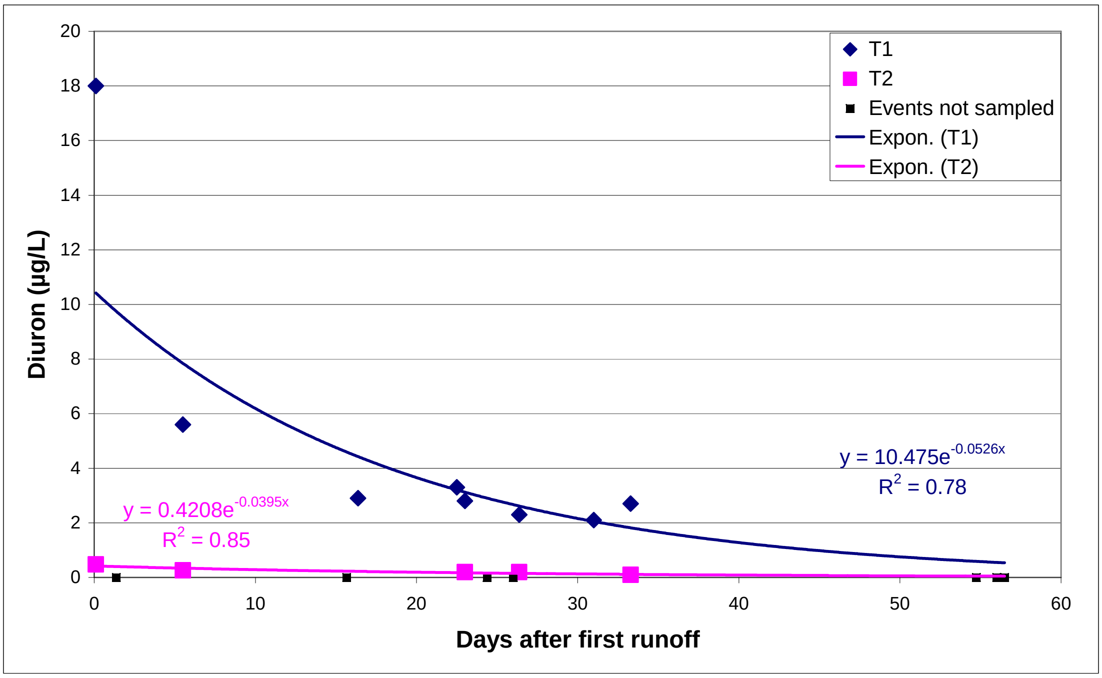

**Figure 7 Regression analysis of diuron concentrations in runoff from the Victoria Plains site**
(Note: log plot of this graph is contained in Section 7.2. Diuron applied to T1 only)

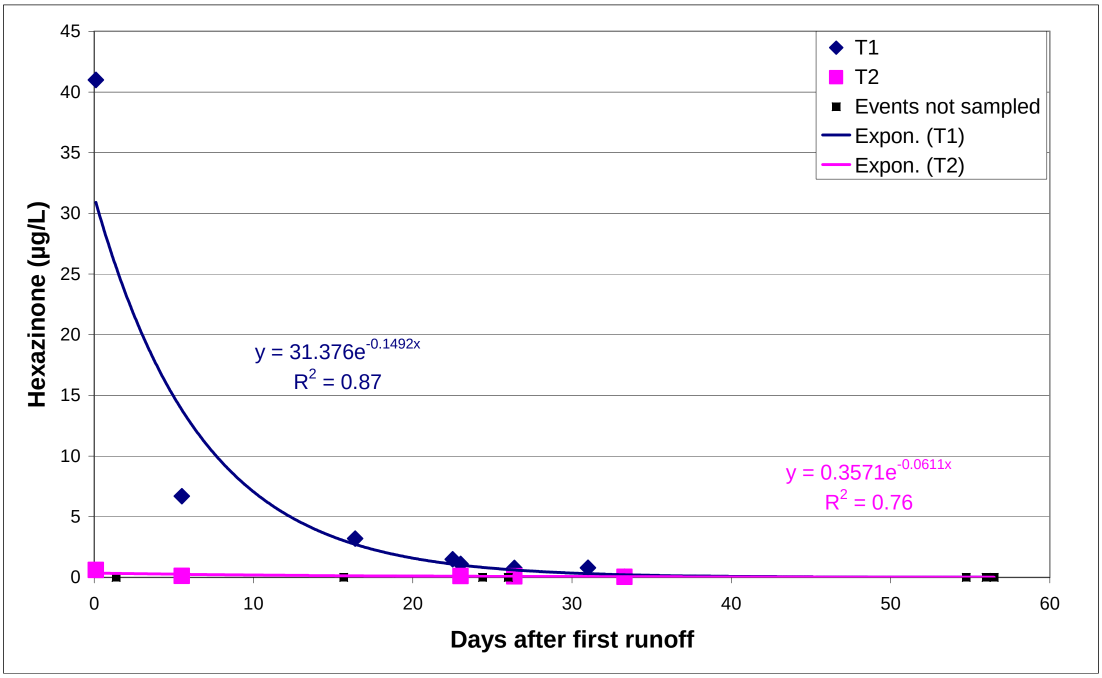

**Figure 8 Regression analysis of hexazinone concentrations in runoff from the Victoria Plains site**
(Note: log plot of this graph is contained in Section 7.3. Hexazinone applied to T1 only)

### *3.2.5.2 Treatment 2*

Only five rainfall and runoff events produced enough runoff on this treatment for herbicide analysis. A mixture of knockdown herbicides Gramoxone (250 g/L paraquat as paraquat dichloride), Baton (2-4 D as dimethylamine salt), MCPA 250 (250 g/L MCPA as sodium salt) and Starane 400 (333 g/L fluroxypyr as the methyl heptyl ester), were applied for weed control (none of which are part of the standard herbicide analysis suite). Trace levels of atrazine (and its breakdown products), diuron and hexazinone were detected in all runoff samples at concentrations of 1 µg/L or lower (Figure 7, Figure 8, and Figure 9). These levels are again thought to be residual concentrations from previous applications.

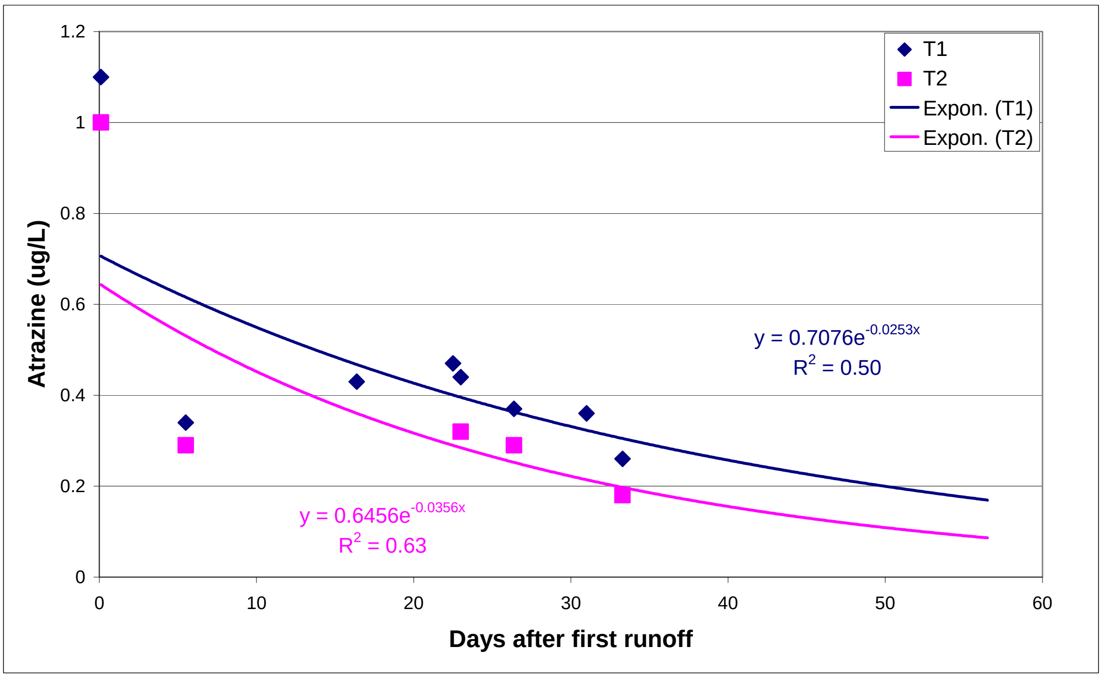

**Figure 9 Regression analysis of atrazine concentrations in runoff from the Victoria Plains site** (Note: atrazine was not applied to either treatment as part of this project)

### 3.2.6 Sub-surface herbicides

Soil water was collected twice (at a depth of 0.9 m) from soil solution samplers in each treatment in the wet season, in late January and mid February. Both treatments recorded residual atrazine and its breakdown products in low concentrations with concentrations never exceeding 0.1 µg/L in Treatment 1. In this treatment, concentrations of atrazine and it derivatives were slightly lower at the second sampling. Concentrations in Treatment 2 were consistently higher than Treatment 1 for both atrazine and it breakdown products, with the greatest concentration of 1.1 µg/L recorded on February 19th, and may reflect the higher drainage in this treatment (due to reduced runoff).

Despite being applied to Treatment 1, recorded levels of sub-surface diuron were significantly lower than Treatment 2. Treatment 1 recorded diuron concentrations of 0.06 µg/L for both samples, while Treatment 2 recorded concentrations of 0.23 and 0.25 µg/L. Hexazinone was found in higher concentrations from Treatment 1 (2.2 and 1.2 µg/L) where it was applied, than Treatment 2 (0.16 and 0.09 µg/L) where it was not, and the concentration was less in the second sampling.

### 3.2.7 Agronomic

Pre-harvest manual harvesting and weighing revealed no difference in yield results between the two treatments, with an average of 102 tonnes cane/ha. The average stalk count for Treatment 1 was 115,000 stalks/ha and for Treatment 2, 95,000 stalks/ha. Yield and percent recoverable sugar (PRS) information collected during machine harvest and processing also indicated little difference between the two treatments (Table 12).

**Table 12 Machine harvest yield results for the Victoria Plains treatments**

| | Treatment 1 | Treatment 2 |
|---|---|---|
| Cane (t/ha) | 94.8 | 91.4 |
| PRS | 15.73 | 15.65 |
| Sugar (t/ha) | 14.91 | 14.30 |

## 3.3 *Marian site*

### 3.3.1 Rainfall and runoff

The Marian site proved somewhat problematic for accurate water quality sample collection during the 2009/2010 wet season due to persistent flooding at the lower end of the site (primarily Treatments 4 and 1). The first runoff event caused these treatments to flood and remain submerged for several days. Subsequent runoff events caused site flooding several additional times, with at least one event submerging all monitoring sites. Given the slope of the paddock, it is likely that some of the flood waters originated from other cane paddocks and this may have been reflected in the water quality results. To maintain scientific integrity, automatic samplers were switched off during site flooding and samples that were collected after flumes were inundated were discarded. Due to the uncertainty in flow rates through the flumes **nutrient, sediment and herbicide loads were not calculated for this site**.

Thirteen rainfall events causing paddock runoff occurred in the 2009/10 wet season at the Marian site (Figure 10). A rainfall and runoff event was defined as rainfall that caused enough runoff for samples to be collected (>3 mm of runoff). Not all plots ran off for each event. As expected more rainfall was required to produce a runoff event at the beginning of the wet season than later in the wet season when the soil moisture had significantly increased. The first rainfall event causing runoff occurred on January 25th 2010 and the final one was Cyclone Ului which hit the Mackay region on March 21st 2010 (samplers were removed for safekeeping prior to this event, consequently no water quality samples were collected).

A total of 1783 mm of rainfall was recorded at the Marian site between December 1st 2009 and March 31st 2010, with the highest daily rainfall of 231.6 mm occurring on January 31st (Figure 10). Runoff was not recorded when sites flooded and samplers sat in water, however it was difficult to determine this remotely and at times some samplers would be recording runoff and sampling while others remained flooded for several days. Treatment 3 recorded the equivalent of 719.3 mm of runoff. This was determined as the most realistic estimate of runoff across the treatments as the treatment didn't flood in the majority of events, experiencing partial flooding only once in the wet season.

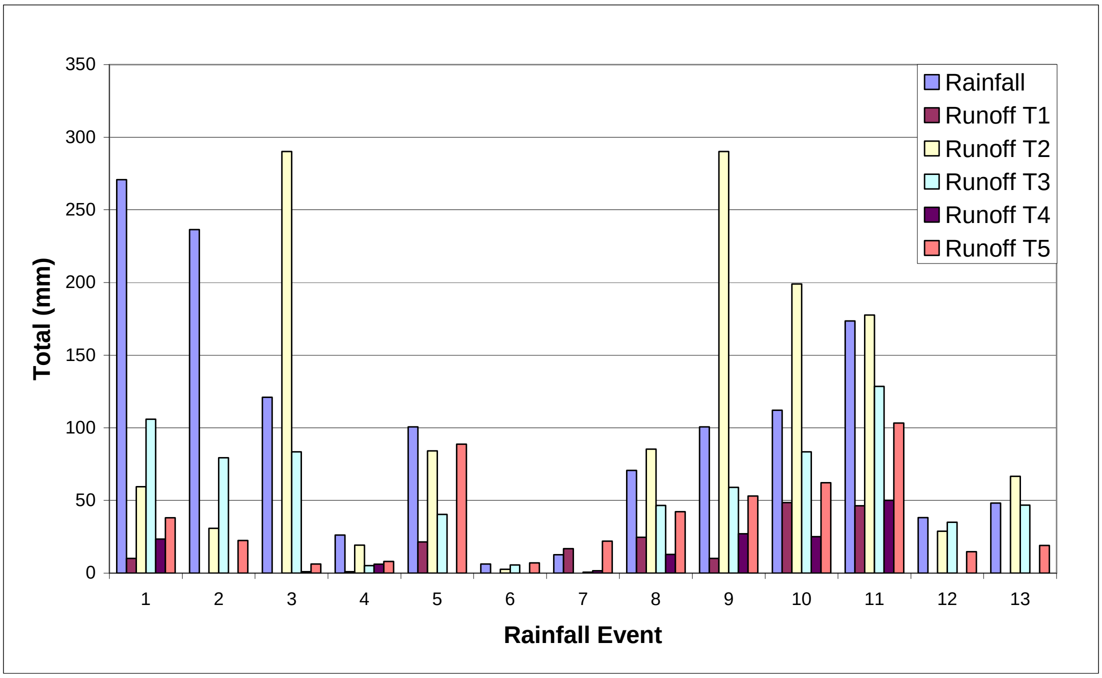

**Figure 10 Rainfall and runoff for the Marian site treatments in the 2009/10 wet season**
(Note: First runoff event was 163 days after cane planting)

### 3.3.2 Total suspended solids, turbidity and electrical conductivity

Total suspended solids concentrations varied considerably across the samples collected (36-330 mg/L), with 78% of samples having TSS concentrations less than 200 mg/L (data not shown). No immediate treatment effects are evident. Treatments 2 and 3 were the most "representative" of the season TSS concentrations, as samples were collected from the most events (six event integrated samples each). Treatment 2 had a slightly higher range of TSS concentrations (39-330 mg/L) than Treatment 3 (36-240 mg/L), leading to a higher mean concentration (142 and 120 mg/L, respectively). Treatment 4 (three samples) had a similar mean concentration to Treatment 3 (119 mg/L, range 96-140 mg/L). Treatment 5 (four samples) had a higher average TSS concentration (143 mg/L, range 73-240 mg/L), and Treatment 1 lower (three samples, mean 92 mg/L, range 62-150 mg/L). When TSS concentrations are summarized into row spacing treatments (Treatment 1 1.5 m; Treatments 2-5 1.8 m; Table 3), the average TSS concentration is lower in the 1.5 m row spacing than 1.8 m row spacing (92 and 132 mg/L, respectively) .

Similar to TSS concentrations, turbidity showed no obvious treatment effects. The turbidity range (64-490 NTU) of each treatment was dependant on the number of samples collected, but the average from each treatment was similar (206-230 NTU). When samples from each treatment were combined, there was a reasonable relationship ($R^2$= 0.75) between TSS concentration and turbidity (Figure 11).

The electrical conductivity across the treatments varied, with an overall range of 48-160 µS/cm. Treatments 2 and 3 had the lowest mean EC (81 and 86 µS/cm, respectively), followed by Treatment 4 and 5 (100 and 108 µS/cm), with Treatment 1 recorded the highest mean EC (133 µS/cm).

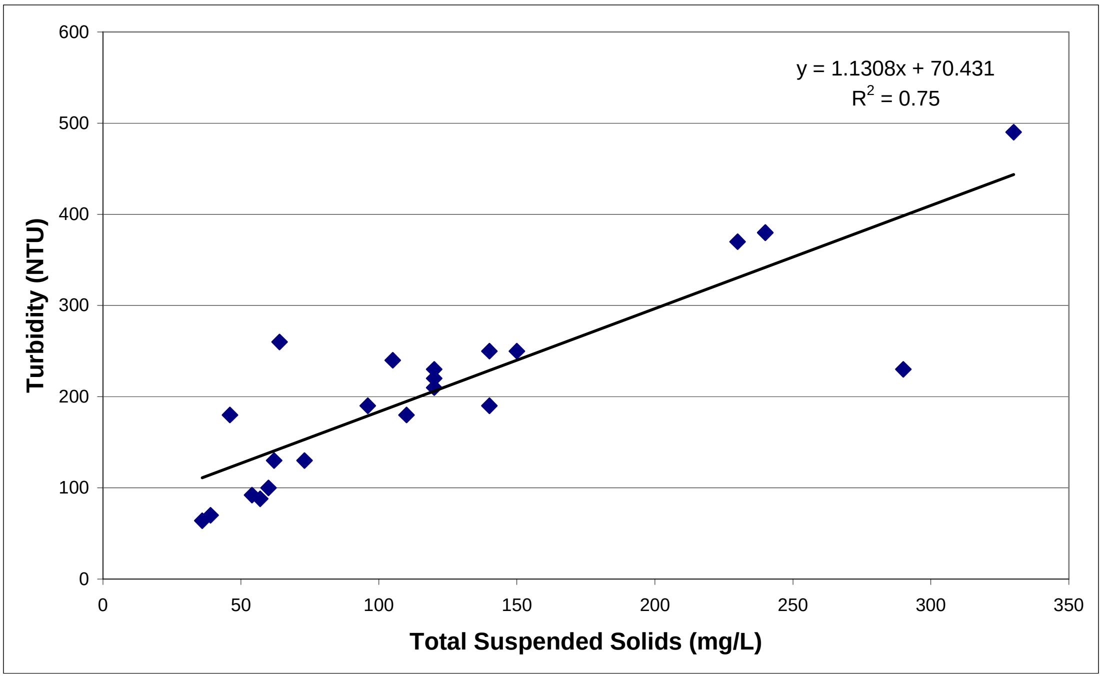

**Figure 11 Relationship between TSS concentrations and turbidity at the Marian site**

## 3.3.3 Nutrients

### *3.3.3.1 Nitrogen oxides*

Despite Treatment 1 and Treatment 2 having the highest applications of nitrogenous fertilisers (190 kg N/ha), Treatment 3 (172 kg N/ha) produced the highest peak concentration of $NO_x$ runoff (523 µg N/L) in the first runoff event, which was more than 100 µg N/L greater than Treatment 2 and more than 250 µg N/L greater than Treatment 1 (Figure 12). Those treatments that have larger data sets appear to show an exponential decline in $NO_x$ concentrations throughout the wet season with similar concentrations being recorded across all treatments by the end of February. The exception to this is during a runoff event in late February where Treatment 1 recorded a $NO_x$ concentration of 499 µg N/L which was 202 µg N/L greater that that recorded from the first sampled event (possibly due to contamination).

Treatment 2 had the most comprehensive $NO_X$ analysis with a range of concentrations between 439 µg N/L and 23 µg N/L, an average $NO_x$ concentration of 126 µg N/L and a median of 72 µg N/L. Treatment 3 had a range of recorded $NO_x$ concentrations between 563 µg N/L and 17 µg N/L with an average of 130 µg N/L and a median of 32 µg N/L. There was little variation in $NO_x$ concentrations recorded from runoff from Treatment 4 (33-36 µg N/L), however no nutrient samples were collected from this site until mid February and then all three samples were collected within an eight day period making this treatment less comparable than the others. Sampled $NO_x$ concentrations from Treatment 5 ranged between 441 and 55 µg N/L, with an average of 183 µg N/L and a median of 81 µg N/L.

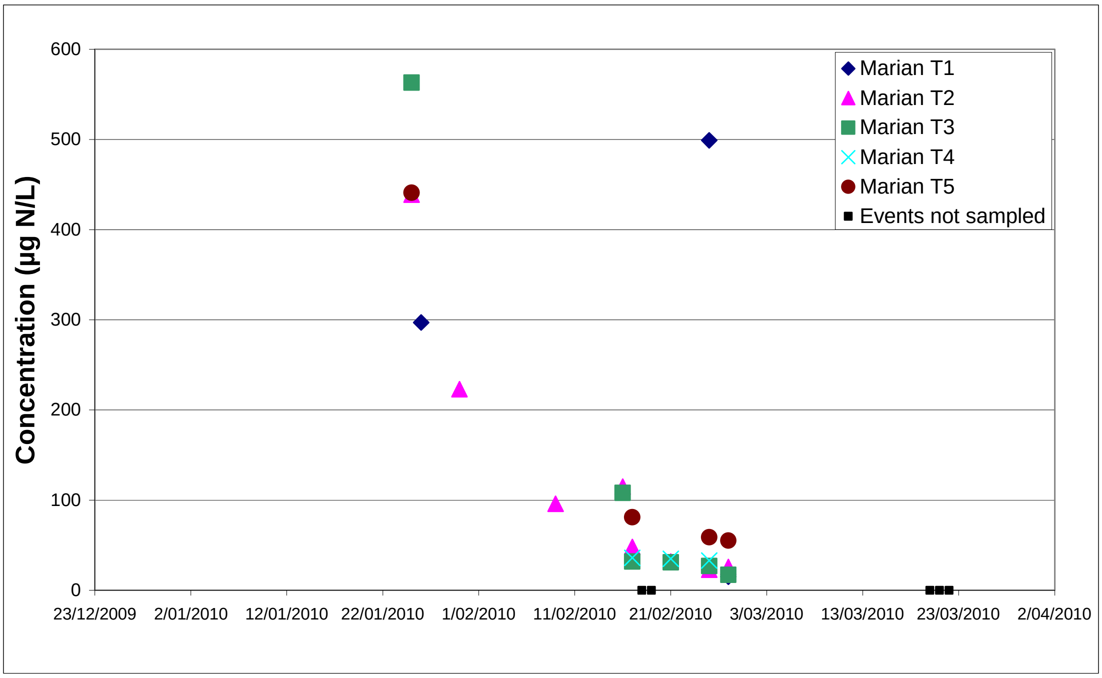

**Figure 12 $NO_x$ concentrations in runoff from the Marian site**
(Note: log plot of this graph is contained in Section 7.4)

#### *3.3.3.2 Filterable reactive phosphorus*

There was a general decline in FRP concentrations in runoff throughout the wet season, although Treatments 2 and 3 recorded subsequent increases in FRP concentrations again by mid-February. The highest concentrations recorded came from the first runoff event where four of the five treatments had measurable runoff and three of these (Treatments 1, 2 and 3) recorded FRP concentrations greater than 1000 µg P/L (Table 13), and more than twice the concentrations in runoff from any other event. The fourth treatment, Treatment 5 only recorded FRP levels of 735 µg P/L from the same event.

**Table 13 FRP concentrations at the Marian site in the 2009/10 wet season**

| | Treatment 1 | Treatment 2 | Treatment 3 | Treatment 4 | Treatment 5 |
|---|---|---|---|---|---|
| Events Sampled | 3 | 8 | 6 | 3 | 5 |
| Minimum FRP (µg P/L) | 189 | 282 | 320 | 221 | 342 |
| Maximum FRP (µg P/L) | 1309 | 1078 | 1022 | 490 | 725 |
| Average FRP (µg P/L) | 563 | 468 | 489 | 347 | 432 |
| Median FRP (µg P/L) | 192 | 409 | 403 | 330 | 355 |

### 3.3.4 Surface herbicides

Herbicides were first sampled in runoff collected 88 days after application. Due to the variability of runoff across the site, the different treatments had different numbers of runoff events that provided enough volume for herbicide analysis. Treatment 1 had two events analysed for herbicides at the end of January and the end of February, with another event earlier in February not providing adequate runoff. Treatment 2 had eight runoff events in the same period that were all analysed for herbicides. Out of the six runoff events that occurred from Treatment 3, three had enough runoff to analyse for herbicides, with the first one being in mid February and following two earlier but smaller runoff events. Treatment 4 had three sampled runoff events but only one was analysed for herbicides in mid February. Treatment 5 experienced five runoff events but only three of these provided enough runoff for herbicide analysis. These were in mid (the second runoff event) and late February.

### *3.3.4.1 Atrazine*

Despite only being applied to Treatments 1 and 2, atrazine and it breakdown products desethyl atrazine and desisopropyl atrazine were detected in runoff from all treatments and in the majority of analysed water samples. Treatments 4 and 5 recorded the lowest concentrations (0.09 µg/L for Treatment 4 and 0.07-0.08 µg/L for Treatment 5), whereas Treatment 3 had runoff concentrations (0.09-0.13 µg/L) that were comparable to the treatments that had atrazine applied (Figure 13). The concentration of atrazine detected in runoff from Treatment 2 ranged from 0.11-0.29 µg/L, with an average concentration of 0.15 µg/L and a median of 0.12 µg/L. The two samples collected from Treatment 1 had atrazine concentrations of 0.17µg/L and 0.13 µg/L.

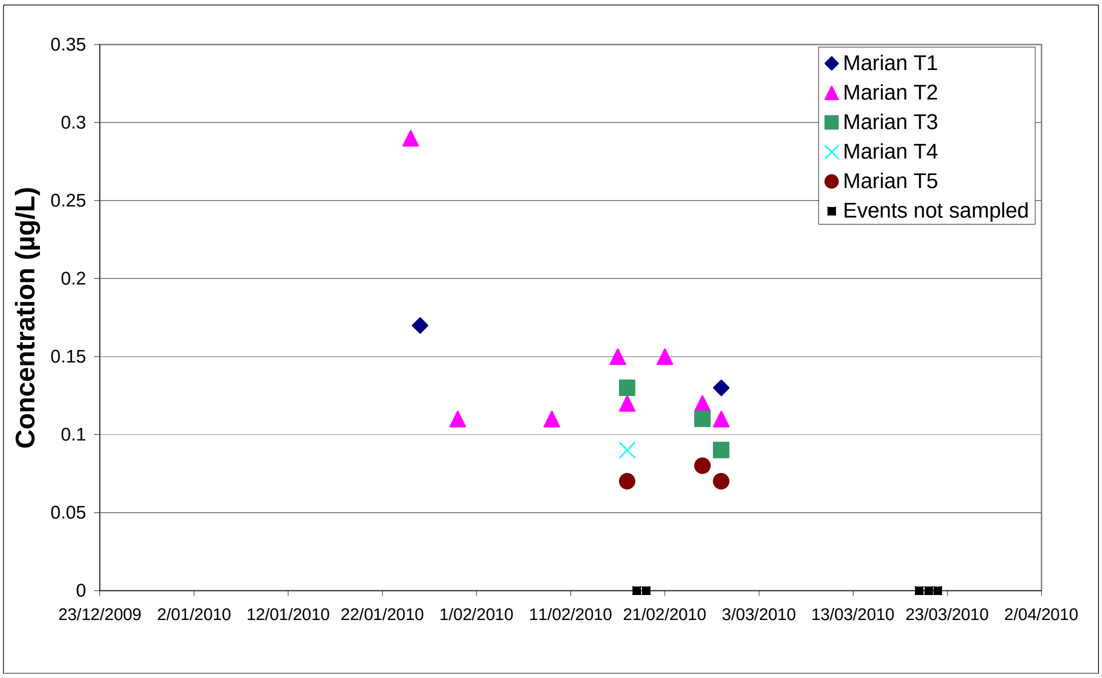

**Figure 13 Atrazine concentrations in runoff from the Marian site**
(Note: atrazine applied to T1 and T2 only)

### *3.3.4.2 Diuron*

The highest recorded concentrations of diuron (0.12 and 0.04 µg/L) were found in runoff from Treatment 1 on two occasions, late in January and late in February (data not shown). All other sites recorded concentrations of 0.02 µg/L or less. Diuron was found in the first five of eight samples analysed for herbicides from Treatment 2, however in each case the concentration was at the limit of detection (0.01 µg/L). Diuron was also recorded once in runoff from Treatments 3 and 4 (0.02 µg/L) and twice from Treatment 5 (0.01 µg/L in each case).

### *3.3.4.3 Hexazinone*

Hexazinone was primarily detected in runoff water from Treatment 2 being detected in five of the eight herbicide samples analysed and only at very low concentrations (0.01-0.04 µg/L; data not shown). Four of the five concentrations recorded were 0.01 µg/L, the limit of detection. Hexazinone was detected once in Treatment 1 at a concentration of 0.02 µg/L from the first runoff event. It was also detected once in runoff collected from Treatment 3 again at the lowest detection level of 0.01 µg/L.

### *3.3.4.4 Metolachlor*

Metolachlor was recorded in runoff from all treatments and in all samples collected for each site despite only being applied to Treatment 3 (Figure 14). The maximum concentrations occurred during the first runoff event for Treatment 1 (9.8 µg/L) and Treatment 2 (11 µg/L) prior to the site flooding. Herbicide samples from Treatment 3 were not collected until approximately three, and then four weeks after this as the earlier events did not provide adequate sample for herbicide analysis. The two samples collected from Treatment 1 were one month apart and the concentration of metolachlor decreased significantly (9.8-0.03 µg/L). Eight water samples were analysed for herbicides from Treatment 2 and metolachlor concentrations ranged from 1.2-11 µg/L with an average concentration of 3.05 µg/L and a median of 1.85 µg/L. Three herbicide samples were collected from Treatment 3 (1.2, 1.6 and 1.6 µg/L) and a single one from Treatment 4 (0.65 µg/L). Three herbicide samples were also collected from Treatment 5 from mid to late February (0.23, 0.24 and 0.29 µg/L).

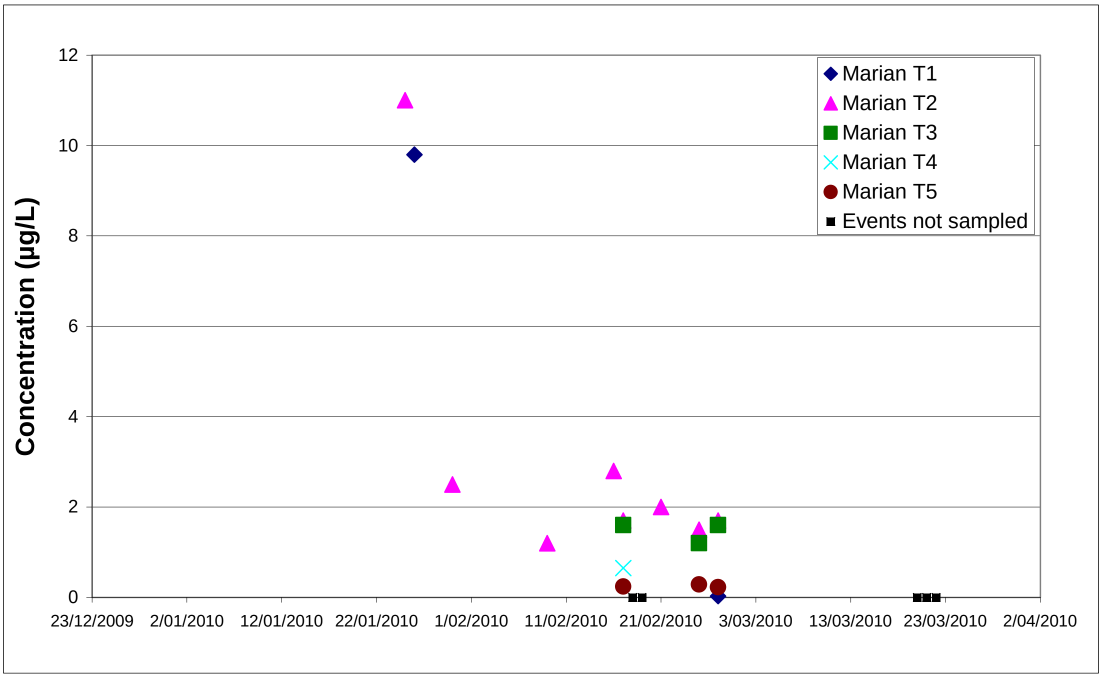

**Figure 14 Metolachlor concentrations in runoff from the Marian site**
(Note: metolachlor applied to T3 only)

### *3.3.4.5 Other herbicides*

Ametryn was the only other herbicide detected in runoff from the five treatments. It was detected in runoff from all treatments at least once, and in concentrations that ranged from 0.01-0.15 µg/L (data not shown). Treatment 4 and Treatment 5 had only a single record of ametryn at 0.02 and 0.01 µg/L respectively. Treatment 1 had two detections of ametryn at the end of January in the first runoff event for this treatment

(0.11 µg/L) and at the end of February (0.02 µg/L). Ametryn was recorded from all eight runoff events from Treatment 2 with concentrations ranging from 0.03 to 0.15 µg/L, with an average and median concentration of 0.06 µg/L. Ametryn was also recorded in all three runoff events from Treatment 3 that had adequate sample volume for herbicide analysis. The first sample was not collected until mid February (0.06 µg/L) and then two samples in late February (0.04 and 0.03 µg/L)

### 3.3.5 Sub-surface herbicides

Two samples were collected from soil solution samplers (0.9 m depth) for each treatment in late January and mid February. Atrazine and its breakdown products were detected in the majority of samples, with the exception of desisopropyl atrazine not being detected in Treatment 3 and only once in Treatment 5. The highest concentrations of atrazine were from Treatment 1 (0.23 and 0.12 µg/L) and desethyl atrazine (0.32 µg/L) from the same sample, although Treatment 4 (no applied atrazine) recorded similar levels (0.20 and 0.12 µg/L). Comparable levels of atrazine were found in Treatments 2, 3 and 5 (1.1 to 0.04 µg/L). Diuron was found in samples from all treatments, but in very low concentrations. In each instance, diuron levels were <0.07 ug/L with the exception of Treatment 1 (0.17 µg/L from the first sample). Hexazinone was again detected in all treatments at least once but at concentrations <0.07 µg/L. Ametryn was detected in all but one sub-surface water sample but at very low concentrations ranging between 0.05 and 0.01 µg/L.

### 3.3.6 Agronomic

Pre-harvest manual harvesting and weighing in August revealed some differences in yield and population between the five treatments (Table 14). The most evident difference was the reduced yield and stalk count from the skip row treatment (Treatment 5). This was expected given that the skip row treatment has only 50% of the treatment area planted to cane.

**Table 14 Manual harvest cane yield and stalk counts for treatments at the Marian site**

| | Treatment 1 | Treatment 2 | Treatment 3 | Treatment 4 | Treatment 5 |
|---|---|---|---|---|---|
| Average cane (t/ha) | 109 | 102 | 123 | 102 | 77 |
| Average stalks/ha | 106,000 | 104,000 | 109,000 | 104,000 | 63,000 |

Due to unseasonal rainfall, the cane at this site was burnt and harvested quite late in the season (late October). Although not in the initial project design the reduced volume of trash allows the site to dry out faster following rainfall and this method was used to reduce water logging while the ratoon cane became established. The yield per hectare and percentage recoverable sugar (PRS) results recorded following harvest are given in Table 15. Again the lower yields are recorded in the skip row treatment (Treatment 5) however the cane yield recorded was significantly greater than half of the other treatments despite it having only 50% of the area planted in cane.

**Table 15 Machine harvest yield results for the Marian treatments**

| | Treatment 1 | Treatment 2 | Treatment 3 | Treatment 4 | Treatment 5 |
|---|---|---|---|---|---|
| Cane (t/ha) | 134.7 | 127.8 | 127.2 | 122.3 | 92.8 |
| PRS | 11.87 | 11.92 | 11.75 | 11.86 | 11.03 |
| Sugar (t/ha) | 16 | 15.2 | 14.9 | 14.5 | 10.2 |

## 3.4 Multi-block and Multi-farm sites

As previously highlighted, there were difficulties with determining flow rates through the Multi-block and Multi-farm weirs when there was sufficient runoff to overtop the drains and spread out into nearby cane paddocks. This problem was more prevalent at the Multi-farm site which overtopped its banks several times throughout the wet season and would remain that way for days at a time. On at least one occasion (the first runoff event) the volume of water flowing through the Multi-farm site drain was so great that it flooded into the Multi-block drain, further confounding flow estimates. During several flow events, water would back up across the Multi-block weir after the downstream dam and channel filled; causing significant flow rates to be recorded when there was virtually no flow across the weir. It was therefore not possible to determine accurate volumes of runoff for events, and consequently loads could not be calculated.

### 3.4.1 Total suspended solids, turbidity and electrical conductivity

There was little variation in TSS concentrations between the sites, and throughout the wet season. At both sites, concentrations were fairly stable even as the wet season progressed and ranged between 68 and 5.6 mg/L, with the one exception being an event at Multi-farm in early February that recorded a TSS concentration more than 20 times greater (1700 mg/L) than all other samples collected. A corresponding spike was recorded in laboratory turbidity for the same event. Excluding the February event, TSS concentrations at the Multi-farm site averaged 34 mg/L while the Multi-block site averaged 37 mg/L, median TSS concentrations at both sites was 32 mg/L.

Turbidity again showed no obvious trend throughout the wet season at either site and measured values were mostly comparable. During four events in the middle of the wet season however, the Multi-block site recorded turbidity levels greater than 100 NTU and there was only one corresponding Multi-farm sample. Excluding the result from the early February runoff event (1800 NTU) the Multi-farm site had turbidity values that ranged from 7.9-130 NTU, with a mean value of 61.5 NTU and a median of 50 NTU. Multi-block turbidity ranged from 51-150 NTU with an average of 93 and a median of 88 NTU. Linear regression curves fitted to turbidity and TSS did not reveal strong correlations between these variables with $R^2$ values of 0.54 for Multi-block and 0.70 for Multi-farm (data not shown).

For the majority of the wet season, EC values were comparable between sites and ranged from 43-120 µS/cm. The highest values were recorded at the beginning of the wet season at the Multi-farm site (240, 175 and 140 µS/cm) with no corresponding samples collected at the Multi-block site. Multi-farm EC ranged from 49-227 µS/cm with an average of 98 µS/cm and a median of 65 µS/cm, while Multi-block recorded an EC range of 43-96 µS/cm with average and median values of 69 µS/cm and 71 µS/cm respectively.

### 3.4.2 Nutrients

#### *3.4.2.1 Nitrogen oxides*

The highest $NO_x$ concentrations recorded at the Multi-farm site occurred in the first runoff event of the wet season (5520 and 1867 µg N/L), while the Multi-block recorded a $NO_x$ concentration that was significantly lower and only mid range for that site (272 µg N/L) in the same event (Figure 15). Peak $NO_x$ concentrations recorded from the Multi-block site were in the following runoff event (1623, 1478 and 1023 µg N/L) almost one month later. Both sites showed a general decline in $NO_x$ throughout the wet season, consistent with the paddock scale sites. The highest $NO_x$ concentrations from Multi-farm were more than twice that of Multi-block, however towards the end of the wet season levels were similar. $NO_x$ concentrations from the Multi-farm site ranged from 12-5520 µg N/L, with an average concentration of 714 µg N/L and a median of 94 µg N/L. $NO_x$ values for Multi-block ranged from 18-1623 µg N/L, with an average of 437 µg N/L and a median of 149 µg N/L.

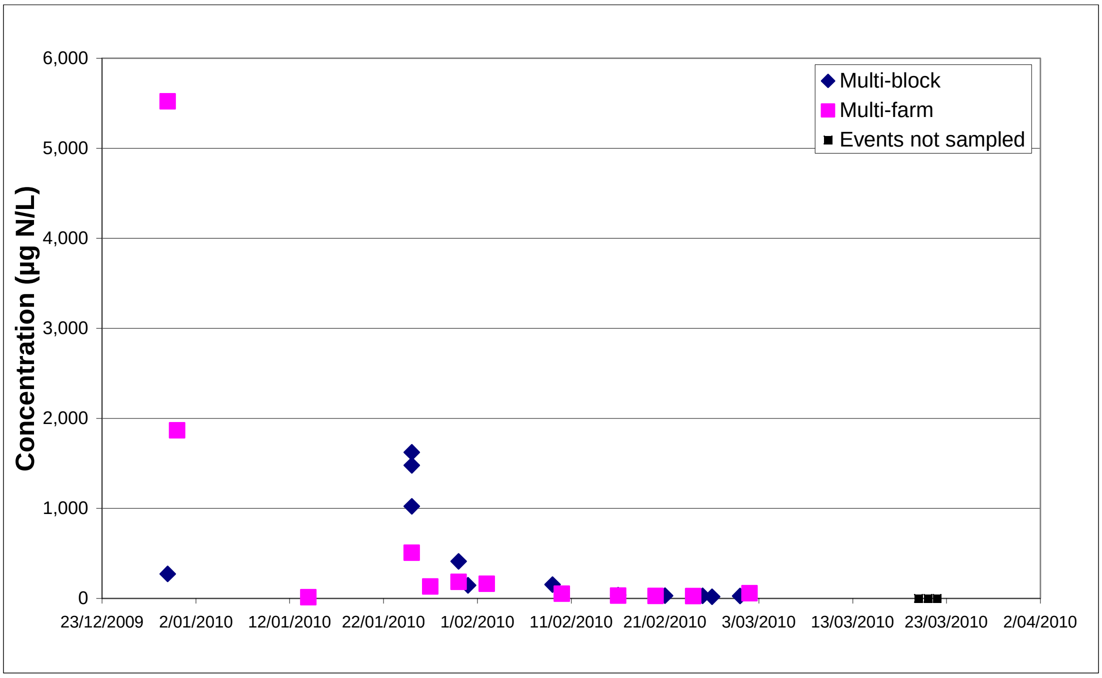

**Figure 15 $NO_x$ concentrations in runoff from the Multi-block and Multi-farm sites**
(Note: log plot of this graph is contained in Section 7.5)

### *3.4.2.2 Filterable reactive phosphorus*

The Multi-block site consistently recorded higher FRP concentrations than the Multi-farm site and for the majority of the runoff events, these concentrations were at least double that of Multi-farm (Figure 16). In one event in late January, several of the Multi-block concentrations were more than four times greater than the single Multi-farm sample. FRP concentrations showed a general decline throughout the wet season, with this trend being more apparent at the Multi-farm site. Concentrations at this scale were significantly greater than in runoff coming from the Victoria Plains site, but similar to those recorded from the Marian site. The concentration of FRP recorded in runoff from the Multi-block site ranged from 469-1208 µg P/L, with an average value of 683 µg P/L and a median value of 632 µg P/L. Multi-farm FRP concentrations ranged from 88-361 µg P/L, with an average concentration of 178 µg P/L and a median concentration of 158 µg P/L.

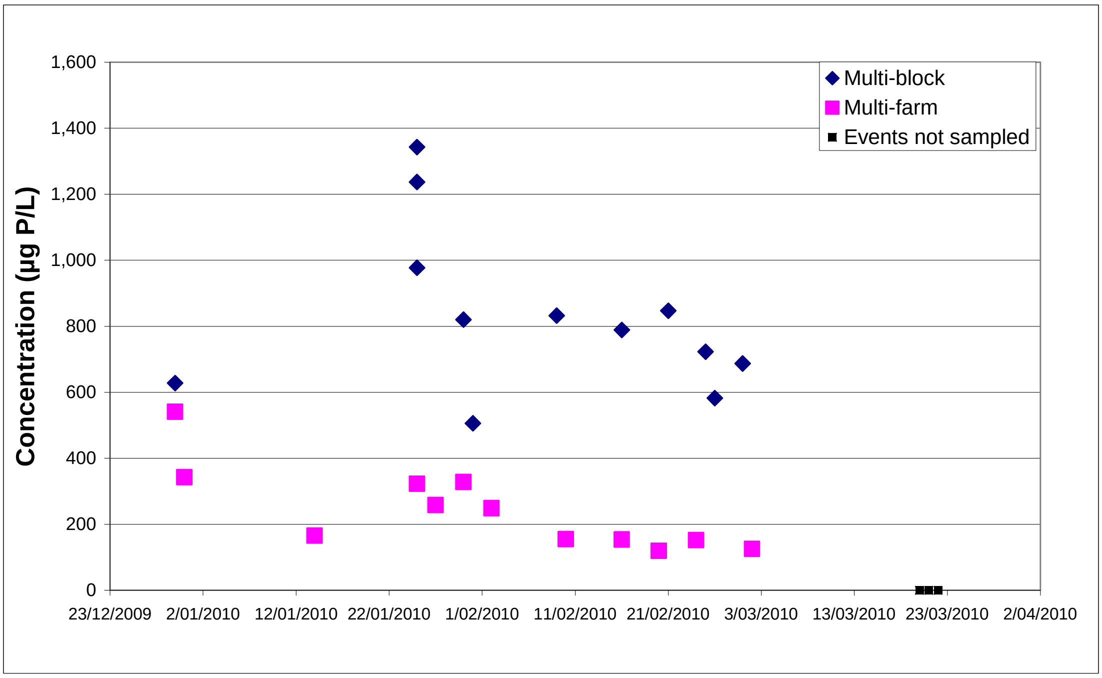

**Figure 16 FRP concentrations in runoff from the Multi-block and Multi-farm sites**

## 3.4.3 Herbicides

### *3.4.3.1 Atrazine*

The concentrations of atrazine recorded in samples collected from both the Multi-block and Multi-farm sites over the 2009/2010 wet season are shown in Figure 17. During some flow events the large volumes of water flowing over the weir resulted in more than one composite sample being collected for analysis. This was the case for all herbicide analysis as a single sample was analysed for the suite of herbicides. Concentrations of atrazine recorded at both sites decreased throughout the wet season, with early records from Multi-farm being 2-3 times greater than those recorded from Multi-block (Figure 17). As the wet season progressed, these differences in detected concentrations declined, however Multi-farm always recorded higher atrazine concentrations. This is not surprising, as atrazine was not applied to the Multi-block catchment prior to the wet season. Atrazine concentrations recorded at the Multi-farm site ranged from 0.07-3 µg/L with mean and median concentrations of 1.07 µg/L and 0.65 µg/L respectively. Atrazine concentrations at the Multi-block site ranged from 0.03-0.54 µg/L with a mean of 0.22 µg/L and a median of 0.15 µg/L. The breakdown products of atrazine (desethyl atrazine and desisopropyl atrazine) were also recorded at both sites but in low concentrations (<0.06 µg/L at Multi-block and <0.35 µg/L at Multi-farm) which again decreased throughout the wet season.

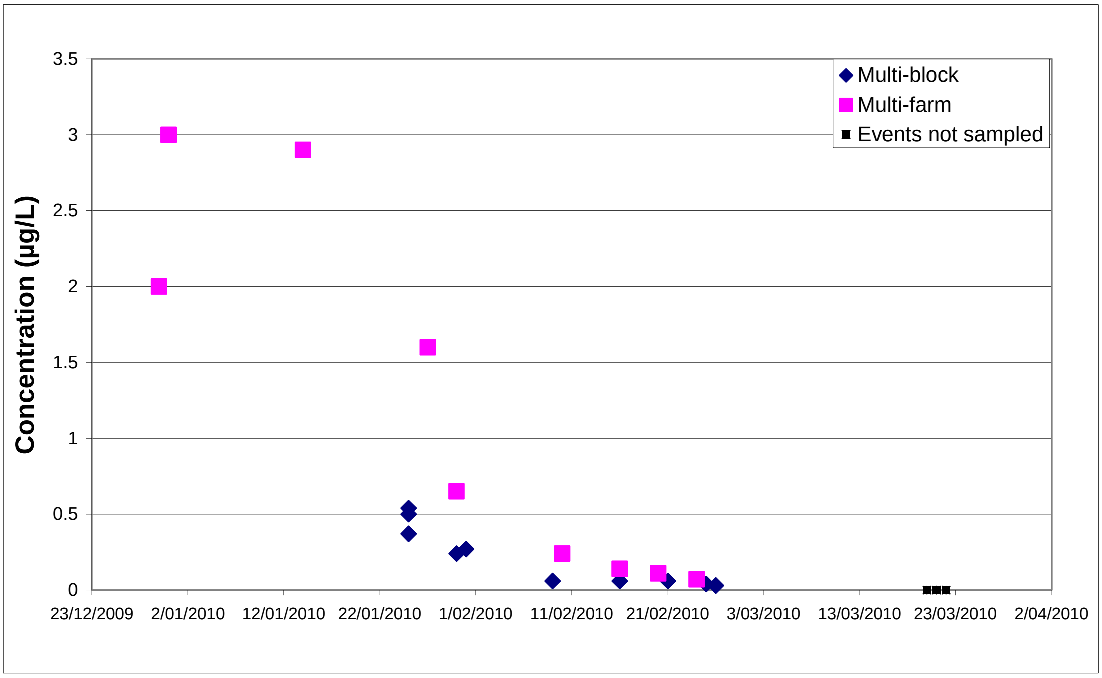

**Figure 17 Atrazine concentrations in runoff from the Multi-block and Multi-farm sites**

#### *3.4.3.2 Diuron*

In contrast to atrazine, concentrations of diuron were always greater at the Multi-block site rather than the Multi-farm site with the three highest recorded concentrations being from a single runoff event (the first for Multi-block with sufficient sample volume for herbicide analysis) over an 11 hour period (Figure 18). Again concentrations of diuron generally decreased throughout the wet season. At the Multi-block site concentrations ranged from 1.1-43 µg/L, with a mean concentration of 11 µg/L and a median of 2.7 µg/L, while Multi-farm recorded a range in concentrations of 0.23-8.3 µg/L, an average concentration of 2.9 µg/L and a median of 1.8 µg/L.

#### *3.4.3.3 Hexazinone*

As with diuron, higher concentrations of hexazinone were recorded at the Multi-block site throughout the wet season with the three highest concentrations occurring during the first runoff event for the site (Figure 19). Hexazinone concentrations recorded at the Multi-block site had a range of 0.26-16 µg/L, a mean of 4.31 µg/L and median of 0.97 µg/L. The Multi-farm site recorded hexazinone concentrations ranging from 0.05-2.9 µg/L with an average of 0.64 µg/L and a median of 0.49 µg/L.

### 3.4.4 Other pesticides

Other pesticides recorded at both sites in low concentrations included ametryn, metolachor and the insecticide imidacloprid. Simazine was found exclusively at the Multi-block site. Ametryn was recorded from the first four runoff events at the Multi-block site in concentrations between 0.01 and 0.07 µg/L and in all sampled runoff events at the Multi-farm site (0.03-0.2 µg/L). Simazine was detected (0.02 µg/L) during the first two runoff events at the Multi-farm site. Metolachlor was detected at both sites in concentrations ranging from 0.01-0.03 µg/L. It was also detected in the first four runoff events at the Multi-block site and the second and fourth runoff events at the Multi-farm site. Imidacloprid was detected only once (0.01 µg/L) at the Multi-block site, but was found in the majority of samples (0.01-0.07 µg/L).

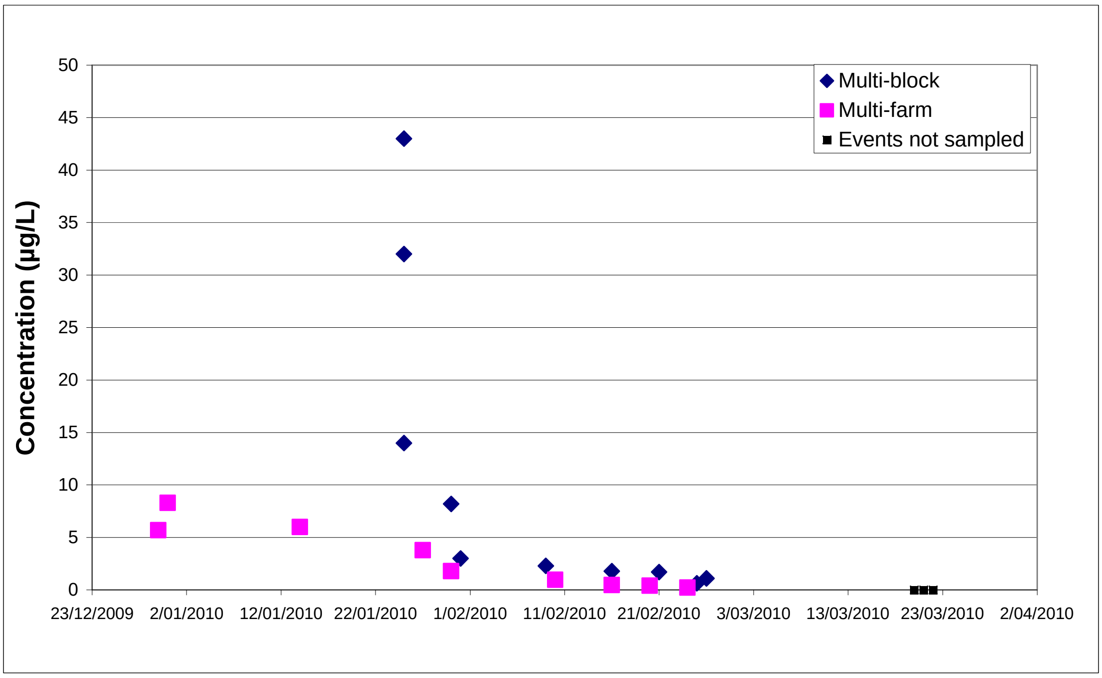

**Figure 18 Diuron concentrations in runoff from the Multi-block and Multi-farm sites**

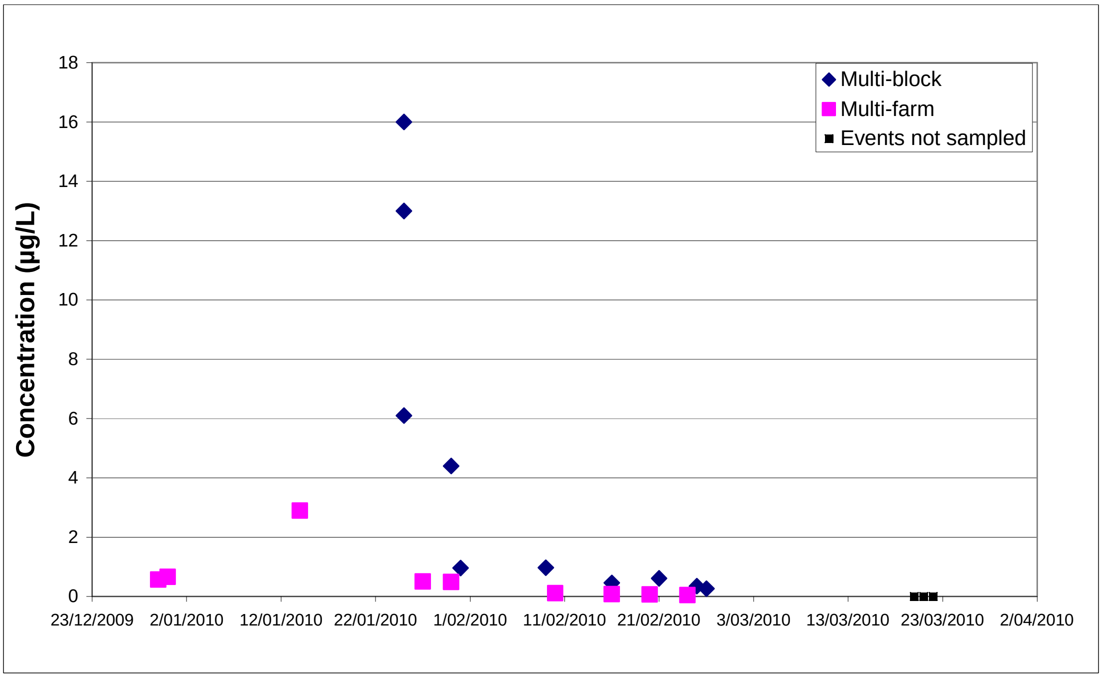

**Figure 19 Hexazinone concentrations in runoff from the Multi-block and Multi-farm sites**

# 4 DISCUSSION

## 4.1 Effects of row spacing/wheel traffic on runoff

The results from the two treatments at the Victoria Plains soil site allow for comparison of row spacing/wheel traffic effects on runoff. Due to the complications from flooding at the Marian soil site, this comparison is not possible.

On the Victoria Plains soil, Treatment 2 (1.8 m row spacing, controlled traffic) had 18% less runoff than Treatment 1 (1.5 m row spacing) across the 2009/10 wet season. The commencement of runoff was delayed by approximately six minutes, and peak runoff rates reduced by 2%. These results are comparable to other soil compaction and controlled traffic studies.

On a heavy clay soil, it has been demonstrated that wheeling (uncontrolled traffic) in a broadacre grain production system produced a large (44%) and consistent increase in runoff compared with non-wheeling (Tullberg *et al.* 2001). In that study, treatment effects were greater on dry soil, but were also maintained during large and intense rainfall events on wet soil. Similarly, non-wheel traffic furrows yielded 36% less runoff than that of wheel-track furrows under conditions conducive to runoff (moist, crusted, bare soil) on a Vertosol (Silburn *et al.* in press). Results from a rainfall simulation study on a Marian soil showed that runoff averaged 43% less from 2 m controlled traffic cane treatments compared to 1.5 m current practice treatments on dry soil, to 30% less on wetter soils (Masters *et al.* 2008; Masters *et al.* in press).

Small reductions in start time to runoff (~6 minutes) and reduced peak runoff rate (2%) are consistent with reduced compaction and improved infiltration. In the rainfall simulation study of Masters *et al.* (in press), they found that the bulk density of current practice treatments (1.5 m) were significantly higher (and hence more compact) in the top 30 cm of the midsection of the cane bed. This reflects the straddling effect of wheels in uncontrolled traffic and therefore greater area of compaction under current practice (1.5 m) compared to controlled traffic (2 m). Although we don’t have bulk density results from our study, it is assumed that similar results will be found.

## 4.2 Factors affecting TSS in runoff

Mean TSS concentrations were similar for treatments at the same site: 92-143 mg/L for the Marian soil site (0.4% slope) and 631-826 mg/L for the Victoria Plains soil site (1.1% slope). The main factors controlling soil erosion are tillage and ground cover (Connolly *et al.* 1997; Prove *et al.* 1995; Silburn and Glanville 2002). Our treatments were all cultivated and had similar cover levels, so it is expected that they would have similar sediment concentrations. The only cultivation difference between the two sites was that the Marian site was ripped twice while the Victoria Plains site was hoed twice. Both sites were plant cane and therefore did not have a trash blanket.

Although seasonal soil erosion can not be accurately determined due to some runoff events not being sampled, it is estimated that soil erosion at the Victoria Plains site was 5-10 t/ha. Historically, soil erosion rates of 42-227 t/ha/year have been recorded in the Mackay region under conventional tillage and burnt cane harvesting (Sallaway

1979). With the move to green cane harvesting, trash blanketing and minimum tillage, soil erosion rates have dropped to <5-15 t/ha/year (Prove *et al.* 1995). Although our study sites where initially bare at planting, the first runoff event occurred more than 150 days after planting, by which time there was full cane canopy closure.

Mean TSS concentrations for our study at the Marian site (92-143 mg/L) are similar to those of the rainfall simulation study of Masters *et al*. (in press) on a similar soil (100-160 mg/L). Our study had high cover levels due to a growing cane crop, whereas the rainfall simulation study had high cover levels due to a trash blanket.

Sediment concentration in runoff is driven by peak runoff rate, cover, and roughness, while peak runoff is influenced by rainfall intensity, runoff depth and cover (Freebairn *et al.* 2009). Their study found that peak discharge was the most important factor influencing sediment concentration (accounting for 41% of variation), as it best represents stream power, a measure of energy available for detachment and transport of soil in runoff. In our study at the Victoria Plains site, there was a general trend of increasing TSS concentration with increasing peak runoff rate ($R^2$=0.33, excluding the event on 30-31st January).

## 4.3 Factors affecting nutrients in runoff

In this study, two main factors appear to control nitrogen and phosphorus concentrations in runoff – amount of product applied (fertiliser) and background soil nutrient levels.

At the Victoria Plains site, the highest $NO_x$ concentration (13,626 µg N/L) was detected in the first runoff event, and from the treatment with the highest applied nitrogen (133 kg N/ha, Treatment 1). This is in comparison to Treatment 2, which had 38 kg N/ha applied, and a maximum $NO_x$ concentration one-third that of Treatment 1. The total wet season loss of $NO_x$ in runoff for Treatment 1 was 13.0 kg/ha, whereas Treatment 2 was 4.85 kg/ha; 9.8% and 12.8% of the applied nitrogen for Treatment 1 and Treatment 2, respectively. A similar cane study near Mossman in far North Queensland also found that the total loss of nitrogen is roughly proportional to the amount of fertiliser applied (Bartley *et al.* 2005; Webster and Brodie 2008). They found that the lower fertiliser rate (98 kg N/ha) lost ~16% of the fertiliser to surface or sub-surface waters, and the higher rate (190 kg N/ha) lost ~15%. This suggests a consistent loss of 10-15% of applied nitrogen (to surface or sub-surface waters) across a number of studies.

Prior to our study at the Victoria Plains site, a fallow soy bean legume crop was grown on both treatments. As a result, soil nitrogen levels were high. Prior to fertiliser application, there was 37 mg/kg of nitrate in the surface soil (Table 6). At the Marian site, the previous cane crop had depleted soil nitrate with 13.2 mg/kg of nitrate in the surface soil (Table 7). The maximum applied nitrogen rate at the Marian site was 191 kg/ha in October, and 133 kg/ha (also applied in October) at the Victoria Plains site. The maximum $NO_x$ concentration in runoff recorded at the Marian site was 563 µg N/L, much lower than the maximum recorded at the Victoria Plains site (13,626 µg N/L), even though it had less applied nitrogen.

Concentrations of FRP in runoff from the Marian site were approximately 20 times that of the Victoria Plains site, despite each site receiving similar concentrations of phosphorus applied at planting (40-50 kg P/ha) and similar amounts of rainfall. The difference is thought to be associated with the different background levels of soil phosphorus. Surface (0-10 cm) soil phosphorus concentrations at the Marian and Victoria Plains sites were 95 and 20 mg/kg, respectively.

## 4.4 Factors affecting herbicides in runoff

Timing of rainfall after herbicide application in this study greatly influenced the concentrations of herbicides detected in runoff water. At the Victoria Plains site, two runoff events occurred within 14 days of herbicide application. These events (11% of seasonal runoff) contributed to 64% of the season’s diuron loss in runoff in Treatment 1, and 91% of the hexazinone loss. The total diuron loss for the season (36 g/ha) was less than 2% of the applied diuron, whereas 9% of the applied hexazinone (49 g/ha) was lost in runoff. Single-event runoff losses of herbicides in the range of 1-2% are not uncommon, however losses greater than this are a result of extreme conditions (Wauchope 1978). Wauchope (1978) defined runoff events within a two week period of application and having a runoff volume which is 50% or more of the rainfall as “critical”. These events almost always produce the bulk of the runoff losses observed for an entire season unless the chemical is incorporated.

Hexazinone was consistently detected in runoff water at higher concentrations than diuron (Treatment 1 at Victoria Plains site), despite three-fold less active ingredient having been applied (528 g/ha compared to 1872 g/ha). This may be attributed to the solubility in water of these chemicals; 33,000 mg/L for hexazinone and 42 mg/L for diuron (Wauchope *et al.* 1992).

Estimating the herbicide residues available for runoff as a function of time after application is complicated. The use of herbicide half-lives in soil is common, but various processes are not always accounted for, such as the herbicide availability and breakdown (volatilisation and photodegradation) on the surface of the foliage and ground cover residues (Wauchope 1978). Therefore “half-lives” based on concentration decline in runoff over time can give more realistic values, as they incorporate all sources of herbicide. Based on the regression equations of Figure 7 and Figure 8, the runoff-available half-lives of diuron and hexazinone (Treatment 1) are 13 and 5 days, respectively.

Although the results obtained from the Marian site were complicated by flooding, there was still a decline in herbicide concentrations in runoff with time. Initial concentrations were much lower than the Victoria Plains site, due to the first runoff event being 88 days after application, compared to 8 days for the Victoria Plains site.

The comparison for the Multi-farm with the Multi-block results for herbicides (diuron and hexazinone) are consistent with modelling results showing an extended peak and lower peak concentrations (Cook *et al.* in press). Atrazine does not fit this model due to nil/low application in the Multi-block catchment compared to the Multi-farm catchment.

## 4.5 Factors affecting sub-surface herbicide concentrations

The limited number of soil water samples collected throughout the 2009/2010 wet season makes it difficult to draw any inferences about herbicide movement or breakdown within soil water. The two samples collected over the four months of the wet season were collected three weeks apart and more than three months after herbicide/ nutrient application. With only two samples, it is virtually impossible to determine whether herbicide levels in soil water at the collection depth of 0.9 m are increasing, decreasing or stabilising and therefore draw conclusions about the sub-surface mobility of herbicides at the sites.

Herbicide concentrations (particularly atrazine, diuron and hexazinone) detected at both sites appeared to be comparable both within treatments and between sites. Victoria Plains treatments were the only ones where herbicide concentrations were detected at concentrations greater than 1 µg/L. The greatest variation within treatments occurred with hexazinone at the Victoria Plains site and was 2.11 µg /L between the first sampling at Treatment 1 and the second sampling at Treatment 2. The greatest variation in herbicide levels from Marian treatments (0.19 µg /L) was for atrazine between Treatment 1 (first sampling) and Treatment 3 (second sampling).

# 5 CONCLUSIONS

Total suspended solids, nutrients and herbicide residues from runoff events from contrasting sugar cane management practice treatments were measured from two soil types at the paddock scale.

At the Victoria Plains site (cracking clay):

- Total runoff from individual runoff events from Treatment 2 (1.8 m row spacing; controlled traffic) averaged 18% less than Treatment 1 (1.5 m row spacing) (665 and 810 mm, respectively from 1636 mm rainfall). Runoff from Treatment 2 was delayed by ~6 minutes compared with Treatment 1, and the peak runoff rate was ~2% lower, all contributing to reduced runoff.
- Total suspended solids (TSS) concentrations varied considerably across the samples and across both treatments revealing no obvious seasonal trends, but increasing peak runoff rates tended to produce higher TSS concentrations. Average TSS concentrations were slightly higher in Treatment 1 (1.5 m row spacing; 826 mg/L) than Treatment 2 (1.8 m row spacing; 631 mg/L).
- Total soil loss is unknown due to some runoff events not being sampled, but it is estimated to be 5-10 t/ha.
- Initial nitrogen oxide ($NO_x$) concentrations in runoff water were three-fold higher from Treatment 1 (133 kg N/ha applied) than Treatment 2 (38 kg N/ha applied). The total wet season loss of $NO_x$ in runoff from Treatment 1 was 13.0 kg/ha, whereas Treatment 2 was 4.85 kg/ha; 9.8% and 12.8% of the applied nitrogen for Treatment 1 and Treatment 2, respectively.
- Filterable reactive phosphorus (FRP) concentrations were similar between treatments (average 31-34 µg P/L), as the same amount of phosphorus was applied to both treatments. Concentrations declined throughout the season.
- Herbicide residues of diuron and hexazinone were particularly elevated in the first two runoff events (within 14 days of application) from Treatment 1 (Velpar K4 applied). These two runoff events represented 64% and 91% of the season's diuron and hexazinone losses, respectively (but only 11% of the runoff). Atrazine residues were detected in both treatments, despite not being applied during our study.

At the Marian site (duplex soil):

- Total runoff was compounded by the site flooding several times, so it is not possible to derive accurate runoff figures. Our best estimate is 720 mm runoff (1.8 m row spacing) from 1783 mm rainfall.
- Total suspended solids concentrations were much lower than the Victoria Plains site (treatment averages 92-143 mg/L), presumably due to the harder setting soil and lower slope at this site.
- Nitrogen oxide concentrations were similar between the five treatments, and showed a decline through the season. Initial concentrations were 400-600 µg N/L, at least 10-fold less than the Victoria Plains site (fertiliser applied to both sites at a similar time). Surface soil $NO_x$ concentrations were three-fold less at the Marian site, contributing to the lower concentrations in runoff.
- In contrast to $NO_x$, average FRP concentrations (347-563 µg P/L) were 10-fold more than those detected at the Victoria Plains site. Surface soil phosphorus levels at the Marian site were more than four times higher than the Victoria Plains site, contributing to the higher FRP concentrations.

- Initial herbicide concentrations were much lower than those detected at the Victoria Plains site, but still declined through the season. Herbicides were applied 88 days prior to the first runoff event, compared to 8 days at the Victoria Plains site.

In summary:

- Results show the importance of soil traits, input application rates, duration between application and the first runoff event, and the value of antecedent infiltrating rainfall or irrigation on nutrient and herbicide losses in runoff.
- Higher nitrogen inputs and high background soil phosphorus levels can lead to larger runoff losses.
- Matching row spacing to machinery track width can reduce runoff.
- The 1.5 m and 1.8 m row spacing treatments produced similar cane yields.

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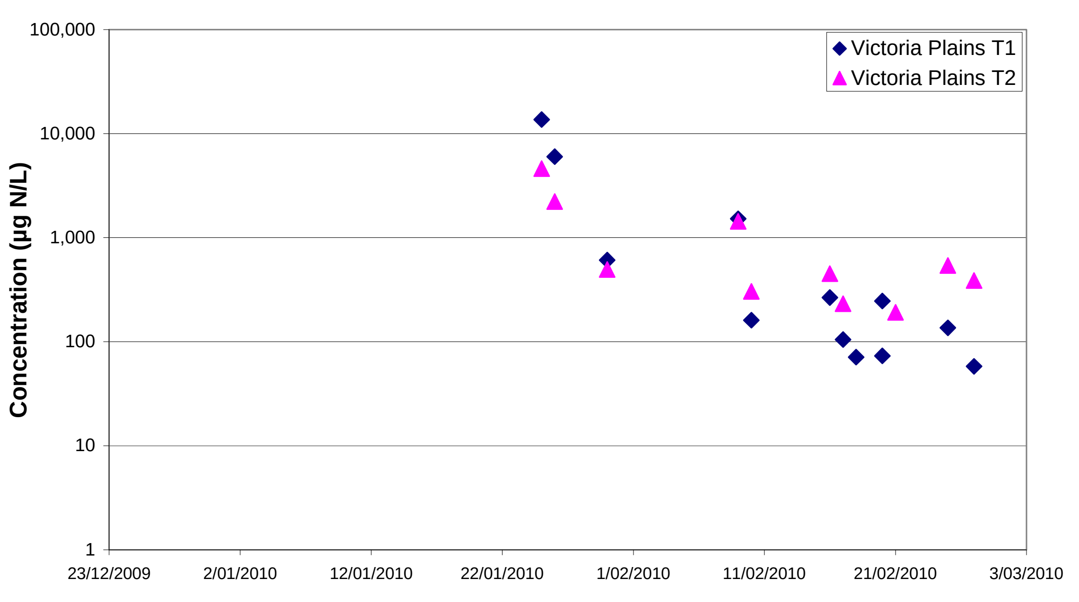
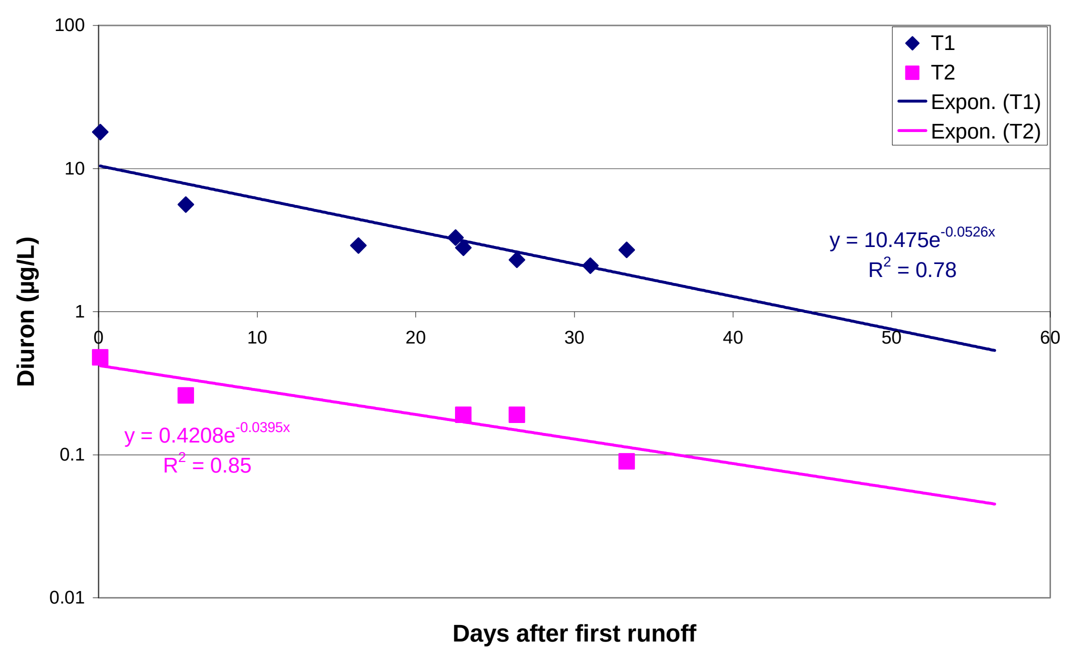
# 7 APPENDICES – Log plots

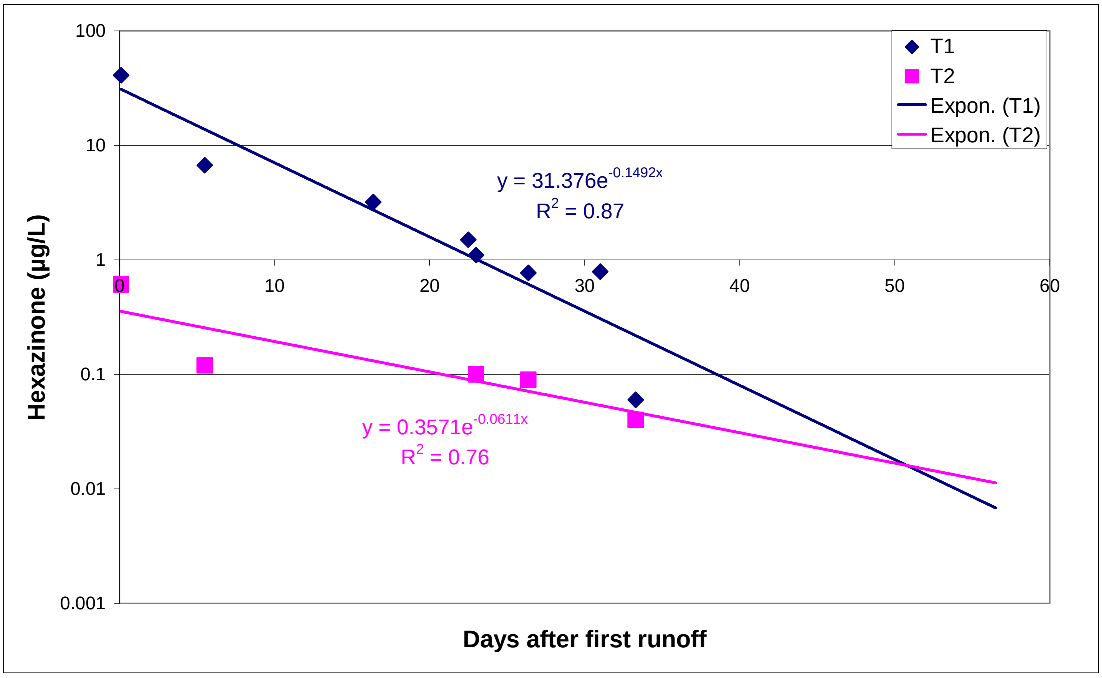
## 7.1 $NO_x$ concentrations in runoff from the Victoria Plains site



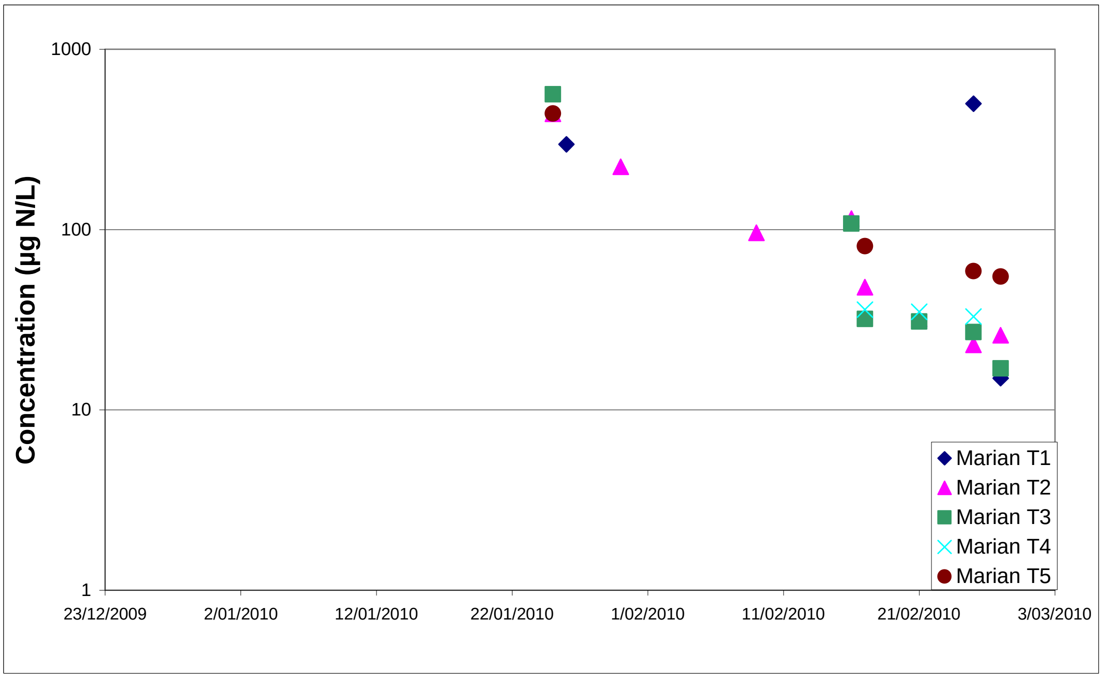
## 7.2 Regression analysis of diuron concentrations in runoff from the Victoria Plains site



## 7.3 Regression analysis of hexazinone concentrations in runoff from the Victoria Plains site



## 7.4 NO$_x$ concentrations in runoff from the Marian site



## 7.5 $NO_x$ concentrations in runoff from the Multi-block and Multi-farm sites